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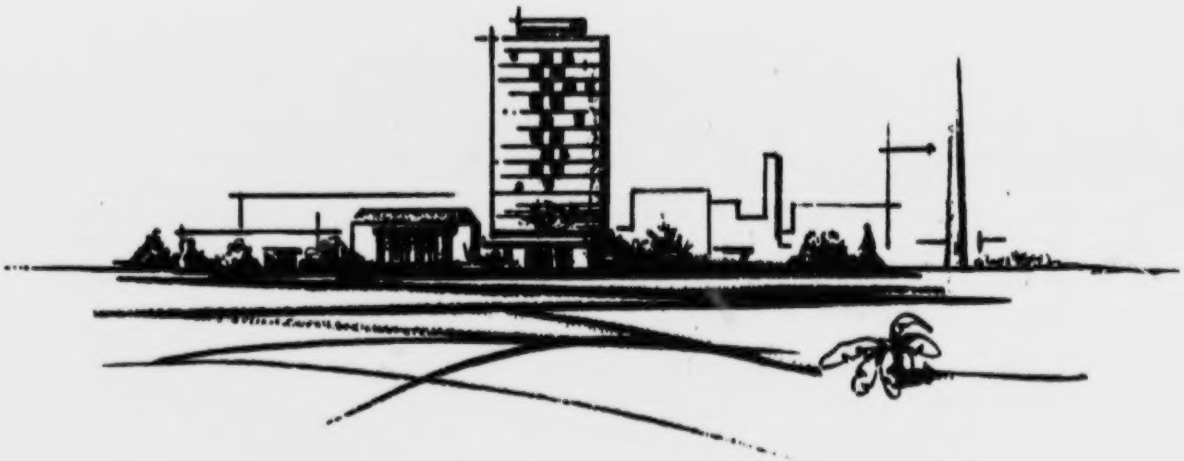

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The concepts embodied in the development and implementation of a comprehensive R & D and program planning capability for EHS were examined. Environmental stressors were selected as the basis for planning rather than categorical approaches. For the mix of complex problems encountered by EHS, a system to establish priorities is required. The integrated planning system which was recommended utilizes mathematical models to assess the impacts of technology upon man and his environment and the assignment of priorities based upon quality of life indices. Specific elements of the management-assistance system which was defined include an overview environmental health planning function to provide coordinated and comprehensive planning in the man-centered ecosystem context; an impact assessment capability based upon a hierarchy of mathematical models; a threat identification function to identify and evaluate potential threats to man and the environment through intensification or extension of current use patterns of products and services or through introduction of new stressors; and an environmental health information network to provide a well-organized information base. A hierarchical approach to the development of mathematical models for prediction of the impacts of stressors upon man and the environment was described and specific examples are presented for lead in the environment.

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on

TECHNICAL, INTELLIGENCE, AND PROJECT INFORMATION SYSTEM FOR THE ENVIRONMENTAL HEALTH SERVICE

VOLUME I. MANAGEMENT ASSISTANCE AND PLANNING

to

U. S. DEPARTMENT OF HEALTH,
EDUCATION, AND WELFARE
ENVIRONMENTAL HEALTH SERVICE

June 29, 1970

Contract No. CPS-69-005

by

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PREFACE

The Consumer Protection and Environmental Health Service (CPEHS) was established by the Secretary of Health, Education, and Welfare on July 1, 1968, to provide "leadership and direction to programs and activities designed to assure effective protection for every American against hazards to health in his environment and the products and services which enter his life".* In CPEHS were combined the Food and Drug Administration (FDA), the National Air Pollution Control Administration (NAPCA), and the Environmental Control Administration (ECA). Both NAPCA and FDA existed as organizational entities prior to the formation of CPEHS, while ECA was organized at the same time as CPEHS was formed. The Administrator of CPEHS reported to the Assistant Secretary for Health and Scientific Affairs, DHEW.

CPEHS was "designated as the lead Federal agency in coordinating efforts to restore, preserve, and enhance the quality of the whole environment of man, as a citizen and as a consumer, as it relates to his health and well-being". Man lives in three intermingling environments: the environment of air, water, and land; the environment of home, work, school, and recreation; and the environment of the products and services he consumes and uses. These environments impinge upon man simultaneously.** Through CPEHS, the environments would be considered together and the partial and uncoordinated efforts to deal with the problems of each could be eliminated.

This particular contract was undertaken with CPEHS on June 30, 1969, and work on the R&D planning system and the information network analysis was initiated. Late in 1969, it was announced that the FDA was to be separated from CPEHS, and on February 1, 1970, the organizational separation was made with FDA reporting directly to the Assistant Secretary for Health. With the departure of one of its significant components and most of its consumer protection functions, CPEHS was renamed the Environmental Health Service.

In this report every attempt has been made to describe the work in terms of the above organizational structure. However, since a significant reorganization took place between the initiation of the work and its completion, some of the activities described may appear unrelated and out of context. This was unavoidable and we hope that the reader will bear with these digressions. The final recommendations in the report for the R&D planning system and the environmental health information network are made specifically to the organizational structure described above. Many of the same recommendations would apply regardless of the name or structure of the organization if its mission and scope were that of EHS.

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*U. S. Government Organizational Manual 1969-70, p 339. Office of the Federal Register, National Archives and Record Service, General Services Administration, Revised July 1, 1969.

**"Strategy of the Consumer Protection and Environmental Health Service", First Edition, October, 1968.

FOREWORD

This report is one of five volumes that were prepared for the Environmental Health Service under Contract Number CPS-69-005. The objectives of this project were to examine research and development program planning needs within the EHS and to develop a management assistance system for the EHS. Since a well-organized and readily accessible information base is essential to the planning, existing information capabilities and facilities within EHS were surveyed and an environmental health information network was devised. Two model case studies for the environmental stressors, lead and persistent pesticides were performed, to serve as examples during the project and to exercise the elements of the management assistance system.

The reports in this series are:

Volume I. EHS Management Assistance and Planning

Volume II. EHS Information Network Analysis

Volume III. Lead Model Case Study

Volume IV. Pesticides Model Case Study

Volume V. Directory of EHS Information Facilities With Selected Supplementary Resources

MANAGEMENT SUMMARY

Implicit in the charge to EHS to establish a better understanding of the ecological system through consolidation of existing knowledge and the acquisition of new knowledge is its R&D function. This particular study is addressed to the concepts embodied in the development and implementation of a comprehensive R&D and program planning capability for EHS. Because the mission of EHS represents a new approach to improving man's environment, i.e., considering man and his total ecosystem, a comprehensive system for planning and action must evolve over a period of several years rather than be implemented immediately. The multidisciplinary and multiechelon nature of environmental programs also influences the rate at which comprehensive planning and action can be achieved. In this study the kinds of components needed were identified and means for their implementation are recommended.

Since man is continuously subjected to stresses from many sources in his environment, it is convenient to plan in terms of environmental stressors. The environmental stressor is that chemical compound or element, biological agent, or physical, social, or psychological condition, reduced to its simplest terms, that has a resultant effect upon man. Within the man-total environment concept, the source(s) of the stressor, the path(s) through which it is transported, the receptor(s) of the stressor, and the ultimate effect(s) upon man must be considered. The chain from source to effect is termed the pollution chain and the source-transport path-receptor portion of it will be referred to as the subenvironment. While actions can be taken to treat the effects of stressors, the solution to environmental problems and the improvement of the quality of man's environment lies at the stressor base. Removal of the cause of an environmental health problem requires elimination or control of a stressor which may transcend many compartments in the environment.

Problem identification from the perspective of environmental stressors is the first important function that EHS must perform in its R&D planning cycle. Once the problems have been identified, some order of priority must be adopted for their detailed examination and solution. Intuitively, those problems that have the greatest impact upon man within the broad EHS mission should receive primary attention. In practice, this involves the application of a value system that includes health, bioenvironmental, and non-health factors. Given the rank ordering of problems, it is then necessary for EHS to develop plans to solve these problems which most effectively use the funds available. This encompasses the ability of EHS and its components to state the objectives and planning assumptions pertaining to each of the problems, to list and evaluate alternative means to accomplish the objectives, and to select an optimum mix of alternatives to form an action program.

No single method for planning and priority setting was found to be totally applicable to the mix of complex problems encountered by EHS. Rather, the current categorical planning activities should serve as the foundation for the development of an integrated planning system based upon quantitative assessments of the impact of technology upon man and his environment. Full implementation of the integrated planning system will require the availability of comprehensive mathematical models to make the assessments and the development of selection or decision criteria based upon the quality of life. A hierarchical modeling approach has been outlined in this study which can take full advantage of submodels developed as a part of on-going research programs of EHS. Although there appears to be a consensus of the attributes of the quality of life, there is presently no good measurement of some of these indicators and no acceptable means to intercompare health, nonhealth, economic, and ecologic impacts. Efforts to develop a value system and metrics for it are required. Until these are available, judgment must be used on the comparability of values in the planning process.

The concept of urgency as a means to establish priorities within the environmental health field was examined. For a given stressor or stressor-subenvironment combination, the urgency to act consists of the number of people affected, the severity of the effect, and the rate of change of each of these quantities with time. Where data on these quantities are not readily available, a simpler index based upon the number of people affected and the severity of the effect may be used as a cursory estimate of priority.

Improvements to categorical planning within EHS can be made through the application of explicit methods to evaluate projects. The objectives of EHS should be decomposed into a hierarchy of successively more specific objectives to which specific projects can be related. Each alternative can then be evaluated with respect to the objective, cost, and other external restraints, and a quantitative performance measure can be assigned to the project. The ultimate goal is to achieve a planning system that minimizes strictly subjective inputs and provides quantitative measures of performance of listed alternatives to the decision maker.

A well-organized information base is essential to supply inputs to the planning process. Existing EHS information resources, including the monitoring and surveillance activities, were investigated. A survey was conducted of the documentation systems and libraries to determine their operational characteristics as related to an information network.

The results of this survey, including a limited number of external information resources, are contained in a separate volume entitled "Directory of Information Sources for the Environmental Health Service".

Additional data were obtained through limited personal and telephone interviews at all levels of EHS and its Administrations and through study of EHS documentation.

On the basis of the study, the establishment of an Environmental Health Information Network (EHIN) has been structured, incorporating the existing information and data sources, and also new resources such as the Information Resource Identification System (IRIS) and the Project Information Retrieval System (PIRS).

In structuring the proposed EHIN, it is recognized that other agencies of the Federal Government have established information and data bases which relate to EHS responsibilities. Mechanisms for interfacing and utilizing these resources are suggested. Further, it is recognized that an operational EHIN, structured as a result of this study, may not be immediately achievable. Rather, EHIN represents a concept which EHS should build toward as it is able in order to assist in constantly strengthening its role in protecting man's environment.

Very little analytical response (e.g., state-of-the-art reports, technical compilations, data or design handbooks, and direct answers to technical inquiry) can be expected from the present information resources, both within EHS and outside EHS. EHS should establish Centers of Technical Competence (Information Analysis Centers) for various high-priority threat areas in order to provide the needed analytical capability. In addition, there is a lack of accurate, documented information relative to the identification of sensitive population groups, to the determination of the number of people currently and potentially affected by a stressor, and to the nature and severity of the effect. This represents an information gap which should be filled on a selective basis. Accepted thesaurus building rules should be enforced in all EHS information activities in order to establish some compatibility of the various thesauri in terms of cross-reference techniques and similar devices. Growth of special-purpose information systems, however, should not be stifled by the creation of a unified vocabulary.

Necessary information resources and capabilities for effective analysis and evaluation of threats are so great in magnitude and variety that they cannot be concentrated within any single agency. To cope effectively with the complexities of today's environmental problems, a wide variety of information resources should be utilized. Various facilities probably can justify, and should have, a stand-alone computer capability in addition to access to the central computer facility, primarily for data processing and research purposes. However, with regard to information systems, every effort should be made to strive for compatibility of operations. The computer facility provided for EHS administrative operations, including information storage and retrieval operations, should equal or exceed the capability of the equipment currently employed by the central computer facility, if that facility cannot be made available to EHS.

The specific elements of the management-assistance system recommended to provide support to the R&D and program planning functions and to provide scientific, technical, intelligence, and project information are:

(1) Overview Environmental Health Planning (OEHP)
(2) Inpact Assessment
(3) Threat Identification and Evaluation
(4) Environmental Health Information Network.

The objective of the overview environmental health planning function is to provide coordinated and comprehensive planning in the man-centered ecosystem. OEHP represents a series of steps undertaken at the Service level with the assistance and support of the components of EHS and outside contractors. The activities to be performed as a part of OEHP are to develop problem statements, obtain stressor matrix input, establish decision criteria, construct a relevancy matrix, establish weights of decision criteria, obtain a rank ordering of problems, and determine problem assignments. The final plan is to be reviewed by EHS and the program selection is to be made. A high rate of professional staff effort is required to launch OEHP and would involve 15 people the first year and 17 the second. The level of effort by professionals the third and fourth years are 8 and 6 man-years per year, respectively. The program should continue at 6 man-years per year effort. This activity could be conducted entirely within EHS, entirely by outside contractors, or by a combination of EHS staff and contractors. After the third year, the sole use of EHS staff is recommended.

Assessment of the impact of technology upon man and his environment is important to provide EHS management evaluations upon which policies can be established, planning can be performed, and actions can be implemented. The impact-assessment function would include the collection and development of mathematical models, the analysis of interactions between stressors, and the assessment of the impact of a stressor or combination of stressors on man and various sectors of his environment. If the assessment function is to be limited to EHS needs only, a minimum level of effort by senior professional staff of 3-1/2 man-years per year is recommended. Approximately 1 man-year per year of computer programming support is also required. This activity could be performed within EHS. However, since the level of effort to meet the demands for assessments fluctuates, contract support would be recommended. The assessment function could also be broadened to serve other elements of government and industry. A Center of Technical Competence for Assessment Technology could be established. Since its mission would be broader, a larger staff would be required and would include 4-1/2 to 5 senior professionals, 2 junior professionals, 2 computer programmers, and secretarial support. Operation of the center by a contractor is recommended to accommodate fluctuating work loads efficiently.

The third component of the management-assistance system would be directed at the identification and evaluation of potential threats to man and his environment through intensification or extension of current use patterns of products and services or through the introduction of new chemical, biological, or physical stressors into the environment. The threat-identification function could be performed by a small group of individuals representing physical, chemical, and biological disciplines. Trends or patterns in industrial, urban, occupational, domestic, and recreational areas would be examined to determine whether potential threats existed. If potential threats were identified, detailed evaluations would be made. This latter function could be combined with the previous function for the evaluation phase. The minimum level of effort that would be required on a continuing basis for the threat-identification aspects would be 3 to 5 man-years per year, assuming that EHIN were operational. This identification function could be performed within EHS, but complementary assistance by outside contractors or consultants who may be more closely attuned to trends in the areas noted would be desirable.

The following recommendations are made for the establishment of an Environmental Health Information Network (EHIN):

(a) The network should be a coordinated network consisting of a Project Information Retrieval System (PIRS), a Monitoring, Surveillance, and Intelligence Information System (MSIIS), and a Scientific and Technical Information System (STIS), supplemented by an Information Resources Identification System (IRIS).

(1) PIRS should be a centralized system, operating within EHS. The early establishment of PIRS is urged and should include:

a. Inventory all current and past internal projects.

b. Inventory all current and past external contracts and grants.

c. Inventory all results (reports) produced to date, both internally and by contract and grant. For all future projects, at least one copy of each report should be sent to this facility.

d. Organize the above in such a manner as to make them both accessible and useful to the entire EHS community including EHS management, EHS operational levels, and EHS contractors.

(2) IRIS should be a relatively small operation, maintaining an inventory of information resources and providing switching and referral service both for the use of the entire staff and for referral of other agencies desiring information to the proper portion of the EHIN network. Implementation of IRIS should begin as soon as practicable.

(3) MSIIS and STIS should each remain a federation of centers in a coordinated network structure. Each center or activity should report to the highest authority consistent with its mission, scope, and user audience.

(b) Within the EHS headquarters element, a Director of EHIN should be appointed to represent and to coordinate the interests of the network, not only at the EHS level, but also in interagency and other Federal activities.

(c) The Director of EHIN should be assisted by an Advisory Council composed of the coordinating managers of PIRS, MSIIS, and STIS plus five representatives from the operating levels. The Advisory Council would assure the vitality of the network, determine network requirements for equipment, and recommend establishment, consolidation, or disestablishment of activities within the network.

(d) The Director of EHIN and his Advisory Council should investigate the extent to which information resources dealing with program assistance, training, and demonstration and testing should be established and incorporated into the network.

(e) Structuring of an environmental thesaurus oriented to the needs of EHS should begin. It is strongly urged that the thesaurus be based upon actual content of projects and reports (and eventually S&T literature), rather than be constructed by a conference of experts. While the latter is possible, it is expensive and may result in generalized decisions which may or may not be of practical value in actual practice. Further, it is almost certain that many vocabulary terms of real value to the user S&T community will be missed by such a conference and will need to be integrated at later stages.

Two model case studies were undertaken for the environmental stressors lead and persistent pesticides to investigate and develop the operational plan and staffing table described above. The effectiveness of the system was tested by the case studies, and areas of improvement were detected. Examples of the type of information on environmental stressors that are currently available were provided and the R&D efforts needed to obtain additional data to eliminate or control the hazards from lead in the environment were explored in a preliminary manner. By selecting a specific stressor for study, mathematical modeling, priority rating, and the environmental stressor matrix concepts which were evolved as a part of the overall management-assistance system could be demonstrated and evaluated. Both model case studies also represented a comprehensive review of the environmental aspects of the stressors. The salient features of the two model case studies are described below.

Lead usually occurs as either sulfide ores (galena, PbS) or oxide or carbonate ores (anglesite, $PbSO_4$, and cerussite, $PbCO_3$). Minerals of iron, zinc, silver, copper, gold, cadmium, antimony, arsenic, bismuth, and others may be associated, in varying proportions, in lead ore deposits. The average grade of lead ores mined contains between 3.0 and 8.0 percent lead. Mining, smelting and refining, secondary recovery, and imports are the four main sources of lead in this country. In 1969, mine production of recoverable lead was approximately 500,000 (short tons), with Missouri accounting for 350,000 tons and Idaho 65,000 tons. Mine production in the U. S. during the last ten (10) years has exceeded 250,000 tons annually. The 1969 U. S. supply from mining, primary refining, secondary smelters, and recovery from copper-based scrap amounted to about 1,540,000 tons. During the last decade, the U. S. supply annually has been near or beyond 1,000,000 tons. Extending this rationale to the domestic lead consumption of primary, secondary, imports, and lead in lead ore entering directly into the manufacture of lead pigment and salts, a figure of 1,333,000 tons is obtained for 1969. These figures suggest that even though only a small percentage of lead may enter the environment from the production and consumption cycle, a certain background level of lead would be expected.

An examination of the use pattern for 1969 and the immediate years preceding indicates how lead is added to the environment. Although there have been fluctuations in quantities in the use categories reported, no major changes in the categories themselves have been reported during the last decade. That is, the major uses of lead during 1969 continued to be (in decreasing order) in the production of storage batteries and accessories, gasoline antiknock additives (mostly tetraethyllead), red lead and litharge pigments, ammunition, solder, cable covering, and calking lead. An inspection of the materials requirements and manufacturing processes for the lead-acid storage batteries, e.g., preparation of pasted plates, preparation and assembly of grids, and particle size distribution and grinding of lead oxides revealed cases of lead intoxication in 66 battery-based industries in Pennsylvania. The use of old battery cases for fuel and the resulting lead-containing ash also were identified as environmental hazards of air and soil.

Examination of the use pattern of leaded gasoline additives tetraethyllead (TEL) and lesser amounts of tetramethyllead (TML) indicated that leaded fuels continue to be a major source of environmental lead. Each gallon of today's gasoline contains about 4 grams of lead, which adds up tc 700 million pounds of lead consumed according to gasoline sales. About half of the exhausted lead becomes airborne, that is, each year about 350,000,000 pounds of lead swirls into the atmosphere. The remainder is either not dislodged from the exhaust system or settles on the road surface or adjoining areas. In recent studies leaded gasoline has been identified as the overwhelming contributor of lead pollutants to the atmosphere. Analysis of atmospheric precipitation samples of lead and other metals collected by a nationwide network of 32 stations throughout the U. S. indicated that the concentration of lead in precipitation correlated with the amount of gasoline consumed in the area in which the sample was collected. The above two investigations suggest that leaded gasolines contribute notably to the environmental (soil and water) burden. Red lead and litharge-based paints were identified as an environmental hazard during shipscrapping because of the high temperatures involved in burning off (volatilizing) the spent paint.

Further exploration of the lead-pigment use pattern brought to light the ban on the use of lead pigments in indoor paints. More important, however, it revealed the many instances of pediatric plumbism (pica) in substandard housing areas of our eastern cities, e.g., New York, Baltimore, Cleveland, and Chicago. Factors such as the elimination of lead paint from walls, continuous education and enforcement activities of the city health department, efforts of local pediatric services, establishment of comprehensive health care clinics for children in the susceptible age living in high risk areas, family planning, and an improved social climate have resulted in a drop of almost 50 percent (286 to 141) in pediatric plumbism in Baltimore during two consecutive 3-year periods (1964 to 1966, and 1966 to 1969).

As Chisolm points out, these corrective measures deserve attention when it is realized that total treatment costs for an institutionalized child suffering from severe permanent brain damage may cost approximately $250,000 during a 60-year period.

An examination of the methods of obtaining lead and the diverse uses of lead suggested that the effects of lead on man may be exercised through contact, inhalation, and ingestion. In order to determine stressor → source → transport → path → effect (on man) relationship, an environmental stressor matrix was formulated for lead. The stressor matrix approach appears sufficiently flexible to collect and display information to define the effects that any stressor may exercise, since it permits specification of the medium, the compartment, the portal of entry, target site of action, consequences, and control.

Lead is very slowly absorbed from environmental sources, e.g., soil, water, food, and air, but the gradual accumulation of the element in the body is the basis for progressive toxicity. It was formerly believed that considerable amounts of lead could gain access to the body percutaneously, but this has been refuted; instead, inhalation and ingestion are the two main routes of entry. The average man ingests about 5 mg/yr from drinking water, 100 mg/yr from his diet, and about 15 mg/yr through respiration. Generally, health authorities agree that lead concentration in respired air should be below 150 $\mu g/m^3$ and tetraethyllead (TEL) should be below 50 $\mu g/m^3$. Concentration of lead in ambient air may vary from approximately 0.01 $\mu g/m^3$ to 50 $\mu g/m^3$ (the latter in air along heavily traveled highways).

Although the principal site of lead in the body is the skeleton, many other soft tissues, e.g., brain, lung, heart, liver, kidney, spleen, and muscle have been found to contain 20 to 120 μg of lead/100 g fresh tissue. Teeth are confirmed to have a higher concentration of lead than any of the bones, and the average lead concentration increases with age, e.g., <10 years ca 17 $\mu g/g$ of ash and 50 to 60 years ca 116 $\mu g/g$ of ash. Blood has shown the following lead distribution: erythrocytes 24 $\mu g/100$ g, and plasma 1.5 $\mu g/100$ g. Blood-lead levels approaching 50 $\mu g/100$ g of blood warrant therapy in order to avoid the central nervous system CNS syndrome of adult or pediatric plumbism. Lead is normally found in hair in higher concentrations (on a weight-per-weight basis) than in any other tissue. The determination of lead in scalp hair is a valuable aid in diagnosing chronic or mild intoxication, using atomic absorption spectroscopy. In the distribution of lead in fetal tissues, lead seems to pass from the mother through the placenta to the fetus at the expense of blood.

The average individual is in lead balance, and the body burden of lead is established early in life and does not change appreciably through the life span. Feces and urine excretions, perspiration, and miscellaneous processes, in decreasing order, help to maintain balance. Lead is primarily excreted by the bowel as unabsorbed lead (90 percent), with urinary excretion being about 10 percent of the amount ingested. The amount of lead in the feces is practically equivalent to that obtained through food and lead intake, plus the unresolved portion secreted into the alimentary tract in the biliary, digestive, and mucous secretions.

Both acute and chronic lead poisoning have been recognized in children and adults. Acute intoxication results from the ingestion of metallic lead, soluble lead compounds, and lipophylic compounds (TML and TEL). Symptoms include leg cramps, muscle weakness, coma, impairment of renal function, depression, and death. A syndrome identical with chronic intoxication may develop if sufficient lead is retained after acute plumbism. Chronic intoxication consists of three types: gastrointestinal or abdominal, neuromuscular, and the central nervous system (CNS) syndrome. These may occur separately or in combination. The neuromuscular and CNS syndromes result from intense exposure to lead, whereas the abdominal syndrome tends to result from a slow and insidious developing intoxication. The CNS syndrome has been termed lead encephalopathy and is the most serious manifestation of lead poisoning in children. Blood-lead levels above 50 μg/100 g of blood and a lead concentration in hair of 42 to 975 μg/g suggest chronic plumbism. It occurs rarely in adults and then only following massive exposure to lead fumes or TEL.

Interference by lead in the biosynthetic pathway for the formation of heme may result in encephalopathy. Diagnostic techniques for lead intoxication in children include urinary coproporphyrin, serum delta-aminolevulinic acid, lead in hair, whole blood, X-rays of bone, and urinalysis. Combinations of 2,3-dimercaptopropanol (BAL), ethylenediaminetetracetic acid (EDTA), and edathamil calcium disodium are recommended for treatment of childhood plumbism. Plumbism in adults generally can be detected by blood and urine analyses, determination of delta-aminolevulinic acid (ALA), and urinary coproporphyrin assay. Blood-lead values above 80 μg/100 ml and urinary lead values above 20 μg/100 ml are indicative of active plumbism and require immediate therapy. Adult plumbism, which results primarily from inorganic and TEL intoxication, is treated with EDTA-type chelating agents or penicillinamine.

An appraisal was made of the costs associated with acute lead poisoning of children to determine whether the effects on an environmental stressor upon man could be translated into pecuniary values. Cost estimates were developed for long-term treatment of patients suffering brain damage as children from lead poisoning. The lifetime costs for care and treatment were estimated to be $200,000 to $250,000 for each individual and the annual incidence of children suffering permanent brain damage in the U. S. was estimated at 1,900. Translation of effects of environmental stressors into monetary units appears feasible for stressors such as lead if there are acute exposures. No satisfactory method of handling costs associated with chronic exposures was found in this limited study.

A mathematical model was developed to represent the environmental transport of the stressor lead from several sources with the subsequent intake of lead by man. In particular, the submodels for airborne transport of lead and the lead in the body were developed. The model developed for the airborne transport of lead is used to calculate the airborne concentrations of lead in the atmosphere due to emissions of lead from several sources. The predicted output is for an average steady-state airborne lead concentration, as the model was not developed to predict time-varying airborne lead concentrations.

The submodel, which represents the flow of lead into, within, and out of an individual, was developed in order to predict the distribution and quantity of lead in several body organs. Since measurement of the blood-lead level of an individual is a clinical method of investigating the effect of lead on an individual, the blood-lead levels due to several modes of intake of lead, including inhalation of various concentrations of airborne lead and ingestion of normal and above normal amounts of lead, were calculated.

The lead model study indicates that environmental sources of lead constitute a major source of lead intake, and lead in the ambient air may not contribute materially to the body burden of lead. Considerable information concerning the toxicology of pediatric and adult plumbism was appraised. The biochemical, clinical, metabolic, diagnostic, and therapeutic parameters of plumbism have been discussed.

In this model case study, the stressor lead was investigated specifically. The relative importance of lead compared with other stressors was not evaluated. Thus, the following recommendations are made to implement environmental health criteria concerning lead, based only upon this model case study for lead without the relative importance of lead to other stressors being determined at this time:

(1) Conduct research to determine the chronic effects of lead in the atmosphere on health. To date, definitive information on the effects of airborne lead on health has not been obtained.

(2) Lead overexposure can change certain biochemical functions, but techniques have not been developed to employ these changes for biological monitoring. For example, further studies on ALA metabolism could lead to the development of a technique for detecting subtle biochemical changes caused by intake of lead either by inhalation or ingestion. This ALA screening should be developed so that elevated ALA levels would indicate recent intake of higher than normal quantities of lead.

(3) Research should be conducted to develop more effective therapeutic agents for plumbism, as some chelating agents may produce more harmful effects than the stressor itself. This is extremely important in pica therapy and massive overdoses of lead in industry.

(4) Reexamine the effect of shifting technology in the utilization of lead, e.g., the large-scale use of lead storage batteries in electric cars. Conceivably, this could lead to a reduction in the environmental burden of lead from gasoline additives. The advantages and disadvantages of this shift should be explored from an environmental health point of view and second-order or higher-order factors should be evaluated.

(5) Synergistic effects. Before the environmental character of lead can be finalized, there is need to determine possible synergistic effects of other stressors. For example, oxides of sulfur, nitrogen, and metals that comprise the environmental burden need to be investigated.

The severity of the health and associated economic effects from the ingestion of lead-based paints by children having pica has been recognized. Several large cities have screening programs under way to detect high levels of lead in children. In addition to the several recommendations pertaining to research programs for the stressor lead, the elimination of ingestion of lead by ghetto children having pica is highly desirable, as this mode of intake was shown by the preliminary lead model to yield body-lead concentrations as compared with other modes of intake. Programs should be initiated to locate and remove lead-based paints from ghetto houses and screen all children who may be expected to have elevated lead body burdens.

The preliminary mathematical model developed for this model test case for the stressor lead can be used to quantitatively investigate some of the previous recommendations and as a tool for R&D planning. The model should eventually be developed into a more comprehensive detailed model which will require better data than are available at the present time. Some of these data are:

(a) Chemical forms of lead inhaled and ingested

(b) Assimilation of lead upon entering the body

(c) Elimination rates by body organs

(d) Particle size distribution of inhaled lead

(e) Emission rates of lead sources

(f) Meteorological data, specifically in mining, reclamation, and manufacturing areas.

Because of numerous technical difficulties, DDT was found to be the most reasonable model compound for study. This decision was dictated primarily because of paucity of data regarding environmental effects of other classes of pesticides. DDT is useful because it has been in widespread use longer than any other material and has demonstrated a wide interaction with all of the potential transport pathways for man-made chemicals in the environment. Because it was necessary to restrict the study to DDT, one major conclusion is obvious: sufficient information is not now available about the quantitative mechanisms of redistribution of pesticides in the environment. Specifically, major deficiencies exist in the aerial transport and uptake of pesticides by man, the environmental reservoirs of pesticide storage, the chronic effects of pesticides upon man and wildlife (from the molecular view rather than simply mortality estimates), and the ultimate fate of pesticides.

In the pesticide study it was useful to divide human exposures into two major pathways. The first, the direct pathway, deals with the direct uptake from primary sources of pesticide release. Primary sources were manufacture and application. Human exposure was by inhalation. Dermal uptake and ingestion are secondary features. Accidental poisonings remained about the same even though the frequency of application and the acute toxicity of the new pesticides has increased. These trends suggest that a very credible job of education is being done at the industrial level. Since most of the victims of death from accidental poisoning were children, further reductions could be made by reduction of the total toxicant contents of the home package to below the child lethal dose, where possible, and elimination of those chemicals that cannot be used within the safety margin (e.g., substitution of carbamates and pyrethrians for organophosphate insecticides). Prescription and dispensing pesticides by trained professionals would also reduce accidental deaths. Aerial application accounts for the largest number of deaths and either elimination or control of this method appears worth study.

The second pathway, the indirect pathway, involves human exposure by translocation through the air, water, or food. While more complicated to consider and model, the indirect pathway involves the total biosphere. The general population of the U. S. is exposed by this means. Serious conflicts exist in the data as to which indirect pathway leads to the major store of pesticides in man. On a worldwide basis, the persistent pesticide content of man is remarkably constant. Within the U. S. there are, however, significant racial and geographic differences. Such differences are difficult to explain if food is the major transport pathway to man. The southern population and the southern negro have greater levels of pesticides than the northern equivalent populations. On the basis of this, together with some indirect evidence from residues in animals, it is likely that only 50 percent of the body burden is from food; the remainder may come from inhalation of insecticide aerosols or dust laden with insecticides. If these observations are correct, then control of the human burden of pesticides by control of food residues, as is now practiced, is at best only partially effective.

There is, at present, no evidence to attribute a direct shortening of human life from pesticide exposure. There are suggestions that large amounts of pesticides will increase the frequency of certain tumors in animals. Whether or not pesticides induce cancers in man cannot be settled at present, because there appears to be a dose dependence in cancer induction. Whether tumors or cancers in man can be induced at the low levels presently in foods is not known. These studies suffered from the relatively small numbers of all toxicological experiments and the short term of exposure.

In any event, man is not the animal in the environment most sensitive to pesticides. Animals of the aquatic environment are particularly sensitive because the translocation pathways are highly conservatory of persistent compounds. Persistent compounds become concentrated rather than diluted as residues pass up the food chain. Fish and birds are inherently more sensitive to pesticides than mammals. Fish appear to lack the basic microsomal oxidase enzyme systems, found in all mammals, which detoxify many pesticides. Birds appear to be very sensitive to the steroidal hormone mimicking effects of the chlorinated hydrocarbons. Hormonal effects in man are not known.

Only the soil system appears to be a "safe" repository for pesticides. Conversion to nontoxic metabolites can also be promoted in the soil by anaerobic conditions. The aquatic ecosystem can be protected from pesticides by modifications of agriculture practice to ensure that pesticides are retained and degraded within the soil system. Little hazard to man through the ground water exists.

Finally, while it is possible to model crudely the distribution of DDT in the environment and to suggest ways to reduce the environmental burden of DDT, these efforts will have little direct effect on human health. Advances in protection for aquatic birds and fish can be accomplished. This study suggests that regulation of pesticides on the basis of their hazard to human health is less important than regulation on the basis of their hazard to wildlife. Human health will most likely be improved rather than degraded by emphasis on wildlife, since regulations based upon harmful effects to wildlife will inevitably reduce human exposure. This does not mean that careful evaluation of pesticides for human health hazards is unnecessary. On the contrary, more information is needed. This study suggests that the rate of application and hence long-term residual levels in the environment are best regulated with more concern to wild-life survival. The margin of safety between levels evoking chronic effects in man and environmental levels will increase by this procedure. Man will hence be "safer".

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TECHNICAL, INTELLIGENCE, AND PROJECT INFORMATION SYSTEM FOR THE ENVIRONMENTAL HEALTH SERVICE
VOLUME I. MANAGEMENT ASSISTANCE AND PLANNING

by

D. L. Morrison, D. B. Menzel, K. L. Nielsen, A. A. Levin,
C. W. Hamilton, G. E. Raines, and S. G. Bloom

CHAPTER 1

INTRODUCTION

In part the Environmental Health Service (EHS) has been charged to* "establish a better understanding of the ecological system through consolidation of existing knowledge and the acquisition of new knowledge". Implicit in this charge is the R&D function of EHS. To meet this charge, comprehensive R&D planning must be performed and the actions taken must be followed to assure satisfactory completion. Effective use of existing knowledge must be made to identify the necessary areas for R&D and to prevent duplication of prior efforts. The mission of EHS, to assure effective protection for every American against controllable hazards to health in his environment, is broad, and priorities must be set to allow an effective attack on identified problems within the allocated resources of the agency. However, planning cannot terminate with the identified problems. Instead, the impact of changes in the environment wrought by technology and its applications or the lack of them upon man's health and well-being must be continually assessed. Through such assessments the emerging problems will be identified and appropriate plans can be made for actions to effect their solution or at least to minimize the adverse impacts.

This report is addressed to the concepts embodied in the development and implementation of a comprehensive R&D and program planning capability for EHS. Because the mission of EHS represents a new approach to improving man's environment, i.e., considering man and his total ecosystem, a comprehensive system for planning and action must evolve over a period of several years rather than be implemented immediately. The multidisciplinary and multiechelon nature of environmental programs also influences the rate at which comprehensive planning and action can be achieved. In this report, the kinds of components in the ultimate planning system for EHS are identified. Changes in description of these components no doubt will occur as the system evolves, but the direction toward an integrated planning system should remain unchanged. Steps should be taken immediately to move in this direction. The interrelationships among the various components of the planning system are defined in this report and recommendations on how they may be implemented are made. Examples are presented of the type of results to be expected from use of the information and planning systems.

It should be obvious that since a comprehensive planning system does not currently exist, the examples are only partial solutions to the total environmental health problems. Only parts of the total problem can be examined with existing techniques.

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*"Strategy of the Consumer Protection and Environmental Health Science", First Edition, October, 1968.

The systematics of the approach, however, are illustrated by the examples. Examination of environmental problems by parts or categories is not so ineffective as it first appears. Each environmental stressor has a limited number of significant effects upon man, and critical paths through the source-transport path-receptor chain are usually apparent and lie within a few subenvironments. While synergisms cannot be examined or identified, the historical categorical approaches to environmental health problems represent effective interim solutions. Planning within a man-total environment concept must proceed concurrently with greater understanding of the man - centered ecosystem as a system. The understanding of the system reinforces the ability to plan effectively, and attempts to extend planning methods to include the total environment sharpen the ability to understand the system.

What elements are involved within the man - total environment concept? Man is continuously being affected by environmental stresses from several sources. For the purposes of classification, it is convenient to think of the stresses in discrete units called environmental stressors. The environmental stressor is, then, that chemical compound or element, biological agent, physical, social, or psychological condition, reduced to its simplest terms, that has a resultant effect upon man. Within the man - total environment concept, the source(s) of the stressor, the path(s) through which it is transported, the receptor(s) of the stressor, and the ultimate effect(s) upon man must be considered. This chain from source to effect is termed a pollution chain and the source-transport path-receptor portion of it will be referred to as the subenvironment. There are obviously several foci in the man - total environment concept. Each factor in the pollution chain can serve as a focus of attention. The categorical approaches to environmental quality focus on the subenvironments or problem areas such as air, solid wastes, and urban environments. This aggregation of stressors and effects within a subenvironment is useful in calling attention to broad classes of environmental quality problems. Another focus is upon the effects themselves. This focus is also useful in the delineation of the urgency of environmental problems. Several categories of health effects and economic impacts can be examined. If improvements are to be made to quality of life within the man - total environment concept, the focus must be upon the stressor itself. Actions can be taken to treat the effects, but the solution to the problems lies at the stressor base. The particular action to be taken requires consideration of stressor and the subenvironment, but the specific solution is directed at the stressor. Since EHS is charged with improving the quality of man's environment, its focus must be on the environmental stressors.

A comprehensive R&D and program planning capability within EHS must incorporate, on an institutional basis, the same elements that are a part of any decision-making process. While there are many variations within the decision-making process*, the steps commonly considered are the identification and definition of the problem, establishment of performance measures or value systems, development of a working model of the system, postulation and analysis of alternative courses of action, selection among the alternatives on the basis of priority indices, program planning, and implementation. Each of these steps is treated to some extent in the succeeding chapters of this report.

A well-organized information base is essential to supply the inputs to the planning process. Within an organization of the size and complexity of EHS, it is essential that the individual elements of the information network be compatible Service-wide if an efficient planning operation is to result. This subject was examined in some detail during the course of this project.

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*For example, see Elion, S., "What is a Decision?", Management Science, 16(4), B-172 (December, 1969).

To attain comprehensive planning within the man – total environment concept, there is a requirement for a working model for that system. A single model at the EHS level would be too impractical to manipulate. A hierarchy of models can be developed to give the detail needed at lower echelons, both organizationally and realistically, in the description of the environment, as well as the aggregate of cause and effect relationships needed at higher planning levels. Coherency requires compatible developments at each echelon of the model and level of the organization. Those elements most useful to a given organizational level should be developed, maintained, and operated by that unit. This implies that the higher echelons would be developed, maintained, and operated by the EHS level.

The network and hierarchical concepts that are developed for the information network and the predictive models for the assessment of the impacts of technology on man and his environment apply equally well to the "third element" of the planning capability, the value system which includes priority or rating indices. The selection of a particular course of action depends upon a clear definition of the problem and the alternatives available for its solution. This obviously involves considerable detail and expertise that is available only at the lowest organizational level and in the lowest echelon models. At the EHS level, aggregates of specific problems must be treated to assign broader priorities and to give planning bases. Thus, priority or rating procedures must be consistent from the top of the organization to the bottom, but they will be applied to differing degrees of detail at each organizational level. A systematic approach requires that the results obtained through detailed analyses at the lowest levels be capable of aggregation and integration at higher levels.

The R&D and program planning system of EHS must consist of people and the tools that they use. Judgments on the part of the staff are needed in the selection of the tool appropriate to the task at hand, the analysis of the information available, and the identification, evaluation, and selection of alternatives. Quantitative as well as qualitative information must flow from echelon to echelon. Computer systems can handle the quantitative elements, but the human parts of the system must handle the qualitative aspects within a systematic framework.

The report on this project has been divided into five volumes and has been organized in a manner to show the elements of the EHS R&D and program planning system and their interactions. In this volume, Volume I, the interaction of all elements of the EHS organization and tools used each element are described in the context of the decision-making process. The elements are focused toward the ultimate goal of planning for stressors in the man – total environment context. Recognition is given however to the fact that time will be required to implement that system fully and that decisions must be made in the interim. A logical stepwise implementation of the ultimate system, starting from the existing practices, is presented. Each step represents an improvement in our abilities to plan for man and his total environment. The final sections in this volume deal with organization and staffing of several functions to provide assistance to EHS, and with the overall recommendations of the study. Volume II deals with the analysis and evaluation of EHS information requirements. Because the information base is essential to efficiency within EHS, an environmental health information network is described. This network develops from existing elements the information system needed to support the ultimate R&D and program planning activities of EHS. Two stressor case studies were performed to test the validity of the approach and to determine what specific tools are needed. The lead case is discussed in Volume III and the pesticides case is discussed in Volume IV. Volume V is a directory of EHS information facilities.

CHAPTER 2

RESEARCH AND DEVELOPMENT PROGRAM

Planning and Priorities

INTRODUCTION

The EHS is a multifunctional, multiechelon organization with a broadly defined mission. While its principal focus is on health, EHS interprets health in the broad context given by the World Health Organization, i.e., "a state of complete physical, mental, and social well-being, not merely the absence of disease or infirmity".(1)* In addition to its concern directly with health, EHS is responsible for certain nonhealth activities such as "conservation of natural resources by reducing the amount of waste and unsalvageable materials and by recovery and utilization of potential resources in solid wastes"(2), and "to protect and enhance the quality of the Nation's air resources so as to promote the public health and welfare and the production capacity of its population"(3). In simple terms, EHS is concerned with direct and indirect effects of environment on human health, with the effects of man's activities on the environment and other organisms, and with certain nonhealth factors related to environmental quality.

Since more than half of the budget of EHS is allocated to R&D activities, it is important that EHS carefully plan to use these funds wisely. There are a multiplicity of environmental stressors impinging upon man, and the limited resources of EHS must be directed in the most effective manner to the critical problem areas. Each of the organizational components within EHS must be used effectively in R&D planning, priority setting, and implementation. Since EHS is not the only agency involved in matters of health and environmental quality, proper cognizance and advantage must be taken of R&D efforts elsewhere.

Problem identification is the first important function that EHS must perform in its R&D planning cycle. In many cases this is easy because the problems are obvious, e.g., acute health problems. In other cases, cause and effect relationships are not obvious and may be unknown. EHS must, in its planning efforts, be ever aware of future effects of environmental stressors upon man.

Once the problems have been identified, some order of priority must be adopted for their detailed examination and solution. Intuitively, those problems that have the greatest impact upon man within the broad EHS mission described above should receive primary attention. In practice this involves the application of a value system which includes health, bioenvironmental, and nonhealth factors. The priorities that are set will undoubtedly change with time as our ability to apply a metric or metrics for quality of life improves.

Given the rank ordering of problems, it is then necessary for EHS to develop plans to solve these problems which most effectively use the funds available. This encompasses the ability of EHS and its components to (a) state the objectives and planning assumptions pertaining to each of the problems, (b) list and evaluate alternative means to accomplish the objectives, i.e., establish priorities within the alternatives, and (c) select an optimum mix of alternatives to form an action program.

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* References for this Chapter are listed on p 38.

The mix of problems encountered by EHS within the man-environment context and their complexity suggest that no single method is totally applicable to R&D planning and priority setting. Rather, EHS must build from its current categorical planning activities toward an integrated planning system based upon quantitative assessments of the impact of technology upon man and his environment. This latter system by its very nature is an evolving one, and elements of the former will continue to be needed for input and implementation. In the sections that follow, the overall system for R&D planning is described and the steps that will lead toward the integrated and comprehensive planning activities within the man-environment context (i.e., within EHS) are recommended.

The activities (rectangles) and outputs (ovals) involved in the recommended R&D planning system for EHS are illustrated in Figure 1. The information base is reviewed and evaluated to provide a statement of the problems of the environment. A rank ordering of problems can be obtained by applying selection criteria to the list of problems. Several approaches for this activity are described in the following sections of the report. Further detailed planning is then undertaken to lead to the definition and selection of projects to form the R&D program for EHS. The output of these project activities, of course, provides further data to the information base. This feedback loop implies that planning and priority setting is an iterative process and is attuned to changes in the environment. The cycle is also repeated at least annually to conform to Federal budgeting practices.

Not shown on Figure 1 is the level of detail within any of the activities or outputs or the EHS organizational component that is responsible for the activity. The steps illustrated in Figure 1 are general and are already being followed to some degree by EHS and its components. As the integrated and comprehensive planning system evolves, it is anticipated that EHS would be responsible for those items shown above the dashed line (i.e., the Overview Environmental Health Planning System), while organizational components within the Administrations, Bureaus, and Offices would be responsible for those activities below the dashed line (i.e., the Categorical Planning Assistance System). This, however, does not imply that each component acts independently.

Planning efforts must be carefully coordinated to minimize duplication of effort and to maximize the application of expertise to a particular task. Environmental health problems identified at the lowest organizational level must be communicated upward for consideration, and possibilities for mixes of alternatives across lower organizational elements must be communicated downward in the planning and organizational hierarchies.

DEVELOPMENT OF PROBLEM STATEMENTS

Possible Approaches

There are three approaches that could be followed by EHS to develop problem statements for R&D planning: the environmental stressor approach, the problem area

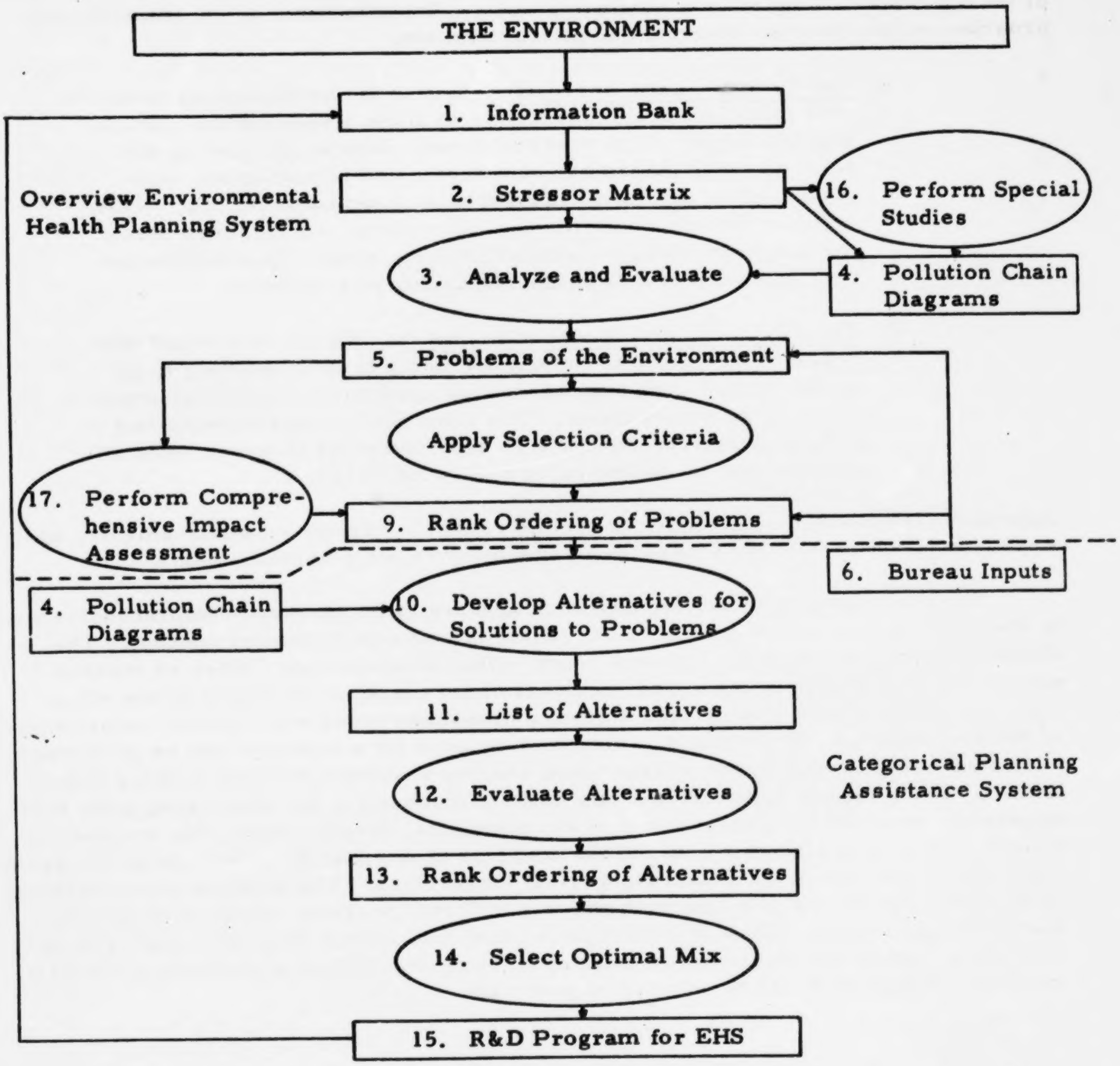
THE ENVIRONMENT
1. Information Bank
2. Stressor Matrix
Overview Environmental Health Planning System
16. Perform Special Studies
3. Analyze and Evaluate
4. Pollution Chain Diagrams
5. Problems of the Environment
Apply Selection Criteria
17. Perform Comprehensive Impact Assessment
9. Rank Ordering of Problems
6. Bureau Inputs
4. Pollution Chain Diagrams
10. Develop Alternatives for Solutions to Problems
11. List of Alternatives
12. Evaluate Alternatives
Categorical Planning Assistance System
13. Rank Ordering of Alternatives
14. Select Optimal Mix
15. R&D Program for EHS

FIGURE 1. ELEMENTS INVOLVED IN R&D PLANNING AND PRIORITY SETTING

or categorical approach, and the ad hoc approach. The last approach is noted for completeness and involves planning for problems brought to EHS by Congress, other Federal agencies or groups outside the Federal government, and for unrecognized environmental problems that have become threats to man. The planning and priority setting system must have the flexibility and capability to deal with these ad hoc situations, regardless of the approaches adopted on a continuing basis. The attributes of the other two approaches within the man-environment perspective are:

(1) *The Problem Area Approach.* This is the traditional approach to environmental health and begins with the identification of major problem areas. The problem areas, such as air quality and solid-waste management, are subdivided into program categories which are then assigned to an organizational unit. This unit has the responsibility for carrying out all functions within that program category and/or problem area. This is the current approach of EHS to the fulfillment of it mission.

(2) *The Environmental Stressor Approach.* EHS is concerned with health in its broadest context and hence must ultimately focus on the impact upon man of various agents (environmental stressors) in the environment. The cumulative effect is important and the dose received from an environmental stressor from all sources and all pathways must be considered.

Approach (1) considers aggregates of stressors within various subenvironments, while Approach (2) deals with the stressors integrated over all subenvironments.

The environmental stressor approach appears to be the more comprehensive route to the improvement of the quality of life within the man-environment concept. The stressor approach explicitly involves cause-effect relationships. When an environmental health problem is identified, removal of the cause or treatment of the effect requires working with a particular stressor which may transcend a given compartment of the environment. In principle, a material balance for a stressor can be performed over man's total environment to determine whether a subenvironment is being overlooked. The stressor approach has this built-in mechanism for eliminating gaps in the knowledge required for improvement of environmental quality. Also, the stressor approach may help to alleviate some of the conflicts of interest that result from the assignment of limited objectives within categorical hierarchies. The solution of one problem often yields the source of a new problem in a different program category or environmental compartment. While it is recognized that EHS cannot adopt this approach immediately, one of the objectives of this report is to describe an evolutionary process whereby the approach can be adopted in good time.

Information Base

The development of problem statements for environmental health planning requires access to relevant past and current information. Scientific and technical information on the flow of each stressor through the environment from its source(s) or point of generation to man must be available in a readily recoverable form to allow identification and evaluation of possible cause and effect relationships. Information on current and past projects within EHS and other agencies within the Federal government must be available to the planner in order to avoid duplication of effort and expenditure of limited resources. Information on the current levels of stressors should be available from monitoring and surveillance networks to determine the severity and urgency of current effects.

Capabilities required to supply this information to the planners within EHS have been thoroughly investigated during this project and the results are presented in Volume II of this report. The Environmental Health Information Network that is described is recommended for this purpose. An environmental stressor matrix is also a convenient method for portraying information on the flow of stressors through the environment; this concept is described in Chapter 3.

RANK-ORDERING OF ENVIRONMENTAL PROBLEMS

General Approach

It is reasonable to expect that the number of environmental problems that can be identified will always be greater than the funds available to EHS to seek their solutions. It is necessary, therefore, that EHS develop methods to establish priorities among the problems and to devote its funds to those having the highest priority. The steps followed in establishing a rating of problems are similar in kind to those followed in rating alternatives within problem areas and projects within the alternatives. If a comprehensive evaluation of the priorities for problems is to be developed, the procedures must be iterative and nested. The implementation of action under one of the alternatives for a given problem may directly affect the merit of an alternative under another problem area. Several iterations within and among the problem areas may be required to select the optimum R&D program.

In this section of the report, the activities relating to the setting of priorities among the problems that have been identified are to be discussed. The subject is simple in concept and priority assessments are currently being made routinely by the decision makers of EHS. The objective of the activities described is to provide a more rigorous, more comprehensive, and more systematic basis for priority assessments within the decision-making process. Improvement of the assessment methods will be an evolutionary process, due in part to the breadth and complexity of the EHS mission, in part due to the organizational and institutional factors in the environmental health field both within and outside of EHS, and in part due to the lack of understanding or agreement on what constitutes the quality of man's environment or the quality of his life. Without the latter there is no quantitative manner to measure the impact of a problem upon man or the success of an alternative undertaken. The discussions in this section of the report are limited to the breadth of the problems facing EHS and to the problems of comparable values for quality. While important, the subject of the organizational and institutional problems is beyond the scope of this project. The recommendations for the assessment methods, however, are basic to the subject of the quality of man's environment and should be applicable regardless of organizational structure.

The essential features of any rating procedure which leads to the assignment of priorities consist of the elements to be considered and the relationships among these elements. A systematic approach to the development of a rating procedure focuses attention upon the following:

Elements - the factors that form the basis for the evaluations.

Objectives - the goals that are desired to be achieved.

Weights - numerical constants that define the relative importance of the objectives.

Alternatives - the different courses of action that can be taken to achieve the objectives.

Performance Measures - the variables in terms of which the results of an alternative are measured.

Costs - the resources required to undertake selected alternatives.

Constraints - exogenous factors outside of the direct control of EHS which limit the availability of resources both in amount and purpose.

Relationships - the formulas used in combining the elements of the rating procedure to yield a measure of the worth of an alternative. These relationships uniquely define the internal structure of the rating procedure. These include:

Scoring Functions - a mathematical rule which assigns a unique numerical worth value to all possible values of the performance measures.

Objective Configurations - a decomposition of broad "high level" objectives into a hierarchy of successively more specific subobjectives to which specific projects can be related

Worth Assessment Rule - a mathematical rule for combining the value assigned by a scoring function to an alternative, the weighted contribution to the hierarchy of objectives, and cost of undertaking the alternative into an overall worth value.

Decision Rule - a criterion function depending on the worth value of the alternative and applicable constraints which lead the decision maker to choose a particular course of action from a set of feasible alternatives.

The above factors establish a framework for communication between those involved in the program planning process. Thus, for example, attention can be focused more easily on those elements which are most critical in a given situation. Also, this framework clearly distinguishes the "subjective" aspects of the procedure, such as assigning weights to objectives, from the "analytical" aspects, such as estimating numerical values for the performance measures.

Since the subject under discussion in this section of the report is the development of methods to assess problems and to rate them, the word problem must be substituted for alternative in the definitions presented above. A problem can be viewed as a situation or action that prevents the attainment of an objective, and the impact of the problem on an objective is a negative performance measure. In principle, the more negative the impact, the more urgent is the need for corrective action and the higher is the priority or ranking of the problem. In the following section of this report, which deals with the rating of R&D projects, the word alternative will be used in the normal sense as defined in the list above. The planning hierarchy which is evolving is that of defining problems and ranking of these problems in order or priority. Then each of these problems may be divided into programs, subprograms, tasks, and projects. In any rating procedure it is necessary to compare like items against the objectives. Problems can be intercompared and evaluated with respect to the highest set of objectives for EHS. Programs can be rated within the problems, project within task objectives, etc. Development of such a multiple rating system eliminates the issue of comparability of specific projects across programs. For example, it is unreasonable to compare the worth value of an R&D project on solid waste with that of a surveillance project on industrial air pollution. This issue stems principally from the fact that EHS subprograms will typically consist of R&D projects, development of standards, surveillance equipment and methods projects, and enforcement projects. The allocation of resources among these types of projects will depend on that aspect of the problem which appears to be most critical. This suggests that comparison of individual project ratings should be internal to the subprogram only. It may not be meaningful to compare such individual projects across programs.

Selection Criteria

The specification of well-defined objectives and the selection of the criteria for rating of problems by EHS is not a simple task. The scope and purpose of EHS activities are broad since it is the "lead Federal agency in coordinating efforts to restore, preserve, and enhance the quality of the whole environment of man, as a citizen and as a consumer, as it relates to his health and well being ... It must strive for a continually expanding comprehension of the complex web of interrelationships between man and his environment in order to develop ways for man to enjoy the fruits of his technology without paying an unnecessary price in physical, mental, and social stress, or in ill health."(1)

In brief, the selection criteria for EHS could well be based upon indicators of the quality of life. While the concept of a quality of life is readily accepted by most people, it defies definition and eludes precise measurement. For the purpose of the present discussion, the quality of life indices will be assumed to be similar in principle to the frequently discussed social indicators(4), national goals(5), and the long-range goals for mankind(6). By making this assumption, the literature available for these indicators can be used as a basis for the assignment of a working set of quality-of-life indices for EHS. It would be presumptuous to recommend a set of quality-of-life indices for EHS on the basis of so short and narrow a study, but this working set can be used to illustrate the utility of the concept in its application to R&D planning and priority setting.

The problem encountered in the definition of quality-of-life indices stems from the fact that we must deal with individuals and groups of individuals. A given individual's definition of the quality of life and those factors most important to him may change with time and place in a manner which is not predictable. Groups of individuals also do not remain homogeneous over long periods of time, and individuals may be members of groups with several purposes not all congruent.

The ranges encountered in the setting of goals for environmental quality are well illustrated in the following excerpt from a Congressional report(7).

> "The overall goal is to restore and maintain the quality of the environment without disrupting the economy and culture... The objectives which make up this goal become subject to quantitative treatment and can be compared as to priority and cost-effectiveness. Their relative importance depends on subjective value judgments but this does not mean that planning and choosing among objectives is not a rational procedure. The spectrum of waste control runs from the desires of some to so purify effluents that they actually enhance the quality of the receiving environment when they are mixed in, to the other extreme of those who would use the assimilative capacity of the environment to contain wastes as long as human health was not affected."

Many lists and descriptions of various social goals or quality-of-life indicators can be found. A few of these are given below as samples of the opinions and judgments of segments of our society on this subject.

(1) "Our standard of living and environmental quality and population are interlocked...there should be a national goal of at least reducing the increase in the rate of our population growth, and upon further study, perhaps seeking to stabilize it as a key factor in restoring and maintaining environmental quality."(8)

(2) "If it is ethical for man to value his chances for survival, to hope for a decent life for his descendants, to respect the value that other men place upon their lives, and to want to obtain the best that life has to offer without prejudicing equal opportunities for others, then the cornerstone of environmental policy is ethical. That cornerstone is the maintenance of an environment in which human life is not only possible, but may be lived with the fullest possible measures of personal freedom, health, and esthetic satisfaction that can be found."(9)

(3) Two basic viewpoints for social indicators were developed by researchers at Stanford Research Institute(10). One viewpoint describes the dimension of the social system by indicators of the quality of social performance and the other the dimension of individuals living within the social system by quality of individual life indicators. This work expanded upon the findings of a HEW Panel on Social Indicators(11), and the list of indices are identical in content if not in title. The indicator areas for individuals and society separately are(10): health; opportunity; environment; standards of living; public safety; learning, science, and culture; and democratic values.

(4) A slightly different list of areas for indicators has been suggested by Gross and Springer(12). These are: electoral participation, civil liberties, democratic participation, individual and group values, learning and education, science and technology, the mass media, art and culture, poverty and inequality, employment goals and the new economics, discrimination against Negroes, social breakdown, crime and delinquency, health and well-being, the natural environment, and urban conditions.

(5) The environmental quality indices suggested by the Environmental Study Group to the Environmental Studies Board of the National Academy of Sciences and National Academy of Engineering(13) are: transparency of the air, purity of the water, the ratio of area of open ground to population, noise level, ratio of wild animals to human population, ratio of area of parks to area of parking lots, and fraction of utility wires above ground.

(6) Achievement and maintenance of an optimum population density has been stated by many, including Hardin(14), as a goal for assuming and enhancing the quality of life. An optimum population density is less than the maximum and cannot be achieved through strictly technical solutions.(12)

These brief excerpts from several publications are not to imply that this is a comprehensive review of the subject of quality of life indices. It is presented to illustrate the type and range of subjects that must be considered in a complete list of quality-of-life indices and that there is some agreement on the topics that should be included. While the final selection criteria for EHS are a matter of policy, it is clear that the quality-of-life indices should ideally be determined through consensus of a group of nationally recognized individuals. The breadth of topics in some of the lists presented above makes them unwieldy for use as examples. A list narrower in scope has been selected for illustrative purposes and concentrates upon the health, physical, and bioenvironmental aspects of the quality of life. In the excerpts presented, little emphasis was given to the bioenvironmental aspects of environmental quality, yet it is a topic of major importance in the overall concept of man and his total environment. From a mission point of view it may also be desirable for EHS to give particular emphasis to health and environmental indicators among its selection criteria.

Table 1 presents a list of possible categories of quality-of-life indicators that have been suggested by others. In the SRI work(10), the subcategories from their lowest attainment category, the minimum level, were generally selected. No attempt has been made to preserve the distinction between individual and society dimensions used by SRI, although this separation may be useful in future analyses. Some additional indicators obtained from several other sources are also given in Table 1. The initial set of indicator categories chosen from the typical categories in Table 1 for illustrative purposes in this study is:

Acute disease
Chronic insults to health
Mental illness
Accidental deaths
Air pollution

TABLE 1. SOME QUALITY-OF-LIFE INDICATORS

Area	Indicator
Health	Free of bed or hospitalization(a)
	Free of incapacitating mental illness(a)
	Number, type, and distribution of public clinics, hospitals, medical services, doctors, in rural and ghetto areas(a)
	Medical care of indigent, aged(a)
	Morbidity in terms of the total impact of illness upon the population(b)
Environment	Air, water pollution below dangerous levels(a)
	Absence of large changes in climate(a)
	Absence of significant changes in plant life(a)
	Presence of adequate shelter(a)
	Absence of dangerous infestation of vermin and other pests(a)
	Adequate safety services: fire, protection, welfare, health, sanitation, utilities(a)
	Depletion of natural resources(a)
	Extermination of wild species(a)
	Prevent loss of structure in earth's ecosystems(c)
Standards of Living	Dollar income considered necessary taking family size and geographical location into account(a)
	Income necessary for reasonable comfort(a)
	Cost of inflation(a)
	Reduction of poverty and establishment of income maintenance programs(a)
	Status of slums, school drop-outism, etc.(a)
	Maintenance of economic growth(a)
Opportunity	Opportunity to gain basic education(a)
	Opportunity to gain employment(a)
	Adequate shelter(a)
	Adequate nutrition(a)
	Minimal comforts of life(a)

(a) Toward Master Social Indicators.

(b) Lee, Philip R., "Health and Well-Being", in Social Intelligence for America's Future, p 441.

(c) Woodwell, G. M., "Effects of Pollution on the Structure and Physiology of Ecosystems", Science 168, 429 (1970). "The loss of structure involves a shift away from complex arrangements of specialized species toward the generalists; away from forest, toward hardy shrubs and herbs; away from the phytoplankton of the open ocean that Wurster proved so very sensitive to DDT, toward those algae of the sewage plants that are unaffected by almost everything including DDT and most fish; away from diversity in birds, plants, and fish toward monotony; away from tight nutrient cycles toward very loose ones with terrestrial systems becoming depleted, and with aquatic systems becoming overloaded; away from stability toward instability especially with regard to sizes of populations of small, rapidly reproducing organisms such as insects and rodents that complete with man; away from a world that runs itself through a self-augmentive, slowly moving evolution, to one that requires constant tinkering to patch it up, a tinkering that is malignant in that each act of repair generates a need for further repairs to avert problems generated at compound interest."

Water pollution
Land use
Natural (nonrenewable) resources
Ecosystem structure
Population
Esthetics
Economics.

Use of the Quality-of-Life Indicators

The selection criteria as defined above in terms of the quality-of-life indices can be used by EHS in three ways. The ultimate comprehensive planning system recommended for EHS will involve the application fo these indices in a rigorous and systematic manner through the use of a hierarchy of mathematical models to assess the impact of technology upon man and his enviornment quantitatively. This comprehensive system will not only establish the priorities among the problem areas but will also lead to the accomplishment of the R&D planning. The implementation of this system must be preceded by the development of a metric for quality of life or the development of metrics or systems of metrics for each of the indicator categories. Another prerequisite is the development or assembly of a hierarchy of predictive mathematical models to use to obtain the assessments in each of the categories. When implemented, this system will provide quantitative values for the current impacts of the problems on man and a basis for evaluating future changes as a result of various alternatives. Although the quality of life indices cannot be completely used in this way at the present time, steps should be taken immediately by EHS to move in this direction.

The second way in which the quality of life indices can be used is through an explicit scheme employing the judgments of the planners within EHS or experts from outside of EHS to show the relevance and importance of the problems that have been identified to these criteria. Although this is a less rigorous method to rate problem areas, it can be employed in the near future by EHS to establish priorities. It requires the planner to examine the problems in light of all of the criteria and to state the basis for making particular selections. The experience gained through attempts to use the quality of life indices even in this qualitative manner will assist in the efforts to obtain well defined metrics for them. It is anticipated that the Service level of EHS will be principally involved with this effort, using the expertise where appropriate from lower organizational echelons and keeping them well informed of the resultant priorities.

It is not realistic to eliminate categorical planning within EHS. At the present, selections of programs and projects are being made with respect to some environmental-quality indices and this should continue while the more comprehensive system is evolving. The expertise in given areas of quality of life rests within the categorical system and the judgments of these people in essence apply the quality-of-life indices to set priorities in an intuitive way. Continuity of programs can be maintained if the indices are used in categorical planning and attention should be given by all planners to these indices.

Each of these ways to employ the quality of life indices in R&D planning and priority setting are described below.

Comprehensive R&D Planning - The Ultimate Method

The ultimate method for comprehensive R&D planning and priority setting involves the combination and the evaluation of alternatives with the assessment of the impact of the identified problem through a hierarchy of predictive mathematical models to obtain quantitative values for the impacts and possible improvements in terms of the quality of life indices. Planning is performed over a specified time horizon, and populations or environmental factors at risk and the severity of the effects are located explicitly in the analysis. Predictive consequences of proposed alternatives are considered and alternative procedures may be employed to obtain not only the priority ranking of the problem but also a rnaking of projects within the problem. Simulation models and data are needed to eliminate many of the judgmental factors that, of necessity, are included in present and interim planning methods, and a fully operational environmental health information network is needed to provide data inputs to planners in an efficient manner.

The operations to be followed in the ultimate method are those presented in Figure 1. Information on an environmental stressor is obtained and pollution chain diagrams are developed to identify in a qualitative manner, the flow of the stressor through the environment. Appropriate mathematical models are selected or developed to give means for quantitative predictions regarding the impact of the stressor. Iteration among these steps will lead to the identification of the problems connected with the stressor and a list of alternative actions is then developed. Each of the alternatives is evaluated to determine the urgency or need for action over the planning horizon. The urgency will then be combined with the probability for success and the cost of the project to obtain the project index.

Under the present project only a few quantitative estimates for the impact of stressors upon human health have been developed. The specifics of the information base, the pollution chain diagrams, and the mathematical models are presented under the model case studies. There is no reason to believe that similar efforts cannot be made to develop estimates for the impact of stressors on other portions of the environment. Isard(15) has developed a method to analyze interactions between economic and ecologic systems by means of an extension of input-output analysis techniques. This appears to be a useful method for deriving economic costs of environmental impacts and should be pursued further to determine the extent of its utility. Kneese(16), Ridker(17), and Lave and Seskin(18) have derived economic costs associated with nonhealth aspects of air pollution. Although all of these assessments of the impacts of stressors upon man and his environment have converted the impact to a dollar cost, there is no a priori reason why impacts cannot be evaluated in terms of other metrics.

Not all of these efforts will have to be undertaken by EHS, but they will have to remain aware of assessment efforts elsewhere in the Federal establishment. Those activities that may be undertaken to provide technology assessments should be directly applicable to the EHS problem. The efforts that are particularly noteworthy at this time are assessments that would be performed under the Daddario bill(19), and the technology assessment methodology programs funded by the National Science Foundation(20). The other NSF programs for interdisciplinary research relevant to the problems of our society(21) should also yield results of direct applicability to EHS. A continuing effort should be maintained within EHS or through a contract organization to remain abreast of these programs and to adapt the results to EHS needs as they become available. Development and refinement of models to predict the impact of stressors directly upon the health of man would be expected to be a responsibility of EHS. Some general guidelines for the development of the methodology necessary to do this are given in the following paragraphs.

The factors incorporated into the ultimate method are:

(1) Population at Risk, $N(t)$ - This is the number of people affected by the alternative as a function of time.

(2) Population Exposure Levels, $E(t)$ - On the basis of the alternative, each person's exposure is calculated as a function of time.

(3) Nature and Severity of Effects, $S(t)$ - This is the potential for causing serious harm to the individual. On the basis of the availability of a standard E^*, the severity can be expressed by $S(t) = F_1[E(t), E^*]$.

(4) Urgency, $U(t)$ - This is a measure of the need for action, depending upon the number of people affected, the severity of the problem, and the trend. If we have $N(t)$ and $S(t)$, then the urgency can be expressed in terms of these and their rate of change with time, $\dot{N}(t)$ and $\dot{S}(t)$:

$$U(t) = F_2[N(t), S(t), \dot{N}(t), \dot{S}(t)] \quad .$$

An evaluation based on these four factors will yield a measure of need for action under the assumption that the most urgent alternative would be ranked first.

The above measure should be combined with the following factors:

(5) Capability in relation to existing knowledge, K

(6) Availability of manpower and physical resources, R

(7) Probability of technical success, P.

If a function or number (K) can be established for existing technical knowledge and a function or number for the available manpower and physical resources (R), then the probability of technical success could be made dependent upon them, i.e., $P = F_3[K, R]$.

(8) Cost: the final factor in the proposed rating scheme.

This is the cost of performing the alternative. The cost could also be made to include the cost of implementation of the results if this is desirable and if the data for its estimation are available.

The several functions described above would be combined to give a value ϕ_a for alternative "a" that could be used in priority setting. The combination rule may take several forms; but, for illustration, it can be represented as the ratio of the urgency or cost to society, U_a, to the costs of accomplishing the alternative, C_a, multiplied by the probability of success, P_a, and the boundary condition, B_a. For alternative "a", the priority index is then

$$\phi_a = \frac{U_a}{C_a} \times P_a \times B_a \quad .$$

These priority indices may be aggregated by problems or stressors to simplify the planning process, but care must be taken in the aggregation process. The urgency may depend strongly upon the alternative under consideration because it includes the changes in number of people affected and changes in severity over a specified planning horizon. These factors may change slowly for one alternative and rapidly for another.

During the course of this project it was not possible to obtain the general functions F_1, F_2, and F_3 but an attempt was made to evaluate the applicability of the concepts. As a part of the lead model case study, specific functions were derived for F_1 and F_2 for a particular problem, and numbers were estimated for K and R. These are described in Volume III. On the basis of the results of the lead case study, it appears that functional relationships can be derived for environmental stressors, and it is apparent that they would follow a general form.

Calculation of Urgencies

Since the urgency function yields a measure of the impact of a stressor upon man and, as such, is an index of priority, it is worthwhile to examine the concept further. It is proposed that a suitable priority index can be given by the equation:

$$U(T) = \frac{1}{T} \int_0^T S(t)\, N(t)\, dt \quad , \tag{1}$$

where

U(t) = the priority index
T = the length of the planning horizon.

This index accounts for both the initial severity of the problem and the expected change in severity over the planning horizon. Through choice of the function S(t), urgencies can be calculated for the alternatives under consideration. One of the alternatives that would be examined is a "no-corrective-action" alternative. With respect to change in severity over time, this index embodies an intuitive sense of urgency. Specifically, it is seen from Equation (1) that U(T) is the average severity over the planning horizon. Thus, for example, if no change occurs in problem severity over the planning horizon, i.e., $S(t) = S$, the priority index will be equal to the problem severity at time $t = 0$ independent of T. Alternatively, if S(t) increases over time, U(T) will increase proportionately. Moreover, in this instance, increasing the planning horizon will increase U(T).

To translate this index into a computational formula, the following assertions are made:

(1) U(T) depends on the population at risk, N(t), and the associated severity, S(t).

(2) The population at risk in time period t, N(t), can be partitioned into k distinct classifications. Each class corresponds to an identifiable risk level. The population at risk in the k^{th} category in time period t is denoted by $N_k(t)$.

(3) The "generalized cost" of a number of the population in classification k is $w_k(t)$.

Given these assertions, the severity in time period t is defined by:

$$S(t) = \Sigma_k w_k(t) N_k(t) \quad . \tag{2}$$

Substituting Equation (2) into Equation (1), the generalized computational formula for the urgency is obtained:

$$U(T) = \frac{1}{T} \int_0^T \Sigma_k w_k(t) N_k(t) dt \quad . \tag{3}$$

This index has several desirable properties from the viewpoint of application. First, the index is essentially a weighted numerical count of the population at risk. Definition of the classes can be made with respect to classification schemes of operating information systems or, alternatively, may be used as a basis for establishing new information system structures. Second, weights, w_k, can be viewed as exogenous parameters which may be determined either subjectively or objectively on the basis of quantifiable cost data. Initially, these parameters may be determined subjectively on the basis of expert opinion; the quality of life weighting described earlier is useful for this purpose. Subsequently, they may be estimated from actual direct and indirect cost data as these data are collected and processed through appropriate information systems. Third, in order to balance short-term needs against long-term needs, it may be desirable to "discount" problem severity over time. Such discounting would have the effect of making the index less sensitive to variations in the length of the planning horizons. Further, the "discount rate", r, could be determined, at least in part, to reflect political factors relevant to urgency for action in solving a particular environmental hazard problem. Adding a discount term to Equation (3) we obtain:

$$U(T) = \frac{1}{T} \sum_k \int_0^T w_k(t) e^{-rt} N_k(t) dt \quad . \tag{4}$$

In the estimation of urgencies for human health effects, the population at risk could be partitioned, by health effect, into several categories such as:

(1) Unrecognized - little or no discomfort

(2) Chronic exposure - over long periods of time may lead to illness

(3) Illness - either from short exposure to high concentration or long exposure to low concentration

  (a) Mild - outpatient type
  (b) Acute - hospitalization but permanent damage not likely

(4) Disability - permanent damage

(5) Death - caused by hazard.

While the first category is of concern, there is little that can be done toward estimating an urgency for it. An estimate of the urgencies in the third, fourth, and fifth categories can be made based upon the observable effects. This has been done in the model case studies and data on the economic costs of the impacts have been estimated to provide some basis for comparison. As better value functions are developed, reliance on cost estimates may not be needed for health effects.

When the comprehensive planning system is implemented, urgency functions would be derived for each of the quality of life indicator categories that relate to the problems. These basic principles embodied in the urgency concept should apply regardless of the category, but the form of the functions and the metric system may vary from category to category.

Use of Value Judgments in Determining Priorities

Several years will be required to implement the planning method just described. Since it is necessary for EHS to act upon and react to problems during the time the quantitative assessment methods are being developed, it is desirable to examine an interim method to obtain priorities for problem areas and to perform R&D planning. In the method that is described below, problem area priority evaluations are separated from the detailed R&D planning activities. An indication of relevance of the problem under consideration to the quality-of-life indices would be obtained, and a ranking of the problem areas by priority would be based upon the judgments of EHS staff and other experts through the application of forced decision methods. This procedure would permit EHS to gain experience in the application of quality-of-life indices in the priority-setting processes and would lead directly into the comprehensive planning activity described previously. These attempts to use the indices in a qualitative manner should sharpen their definition and permit evaluation of the metrics proposed. The existing elements of R&D planning can be preserved in this interim system. A detailed description of the R&D planning is presented in a later section of this Chapter.

Purpose and General Approach

The major impediments to the development of a uniform rating system to establish priorities among the problems encountered by EHS are the diversity among the problems and the breadth of categories among the selection criteria. The diversity of problems could be handled simply, but there is currently no procedure for making comparisons across the several categories of values implicit in the quality of life indices. There are no sets of quantitative values for example, that permit direct comparison of human life or health, loss of ecological structure, and utilization of land for sanitary land fills. Until the quantitative assessment methods and comparable metrics have been developed, expert judgment appears to be the only basis for making comparisons and setting priorities at the present time. Several ways in which expert judgment can be used by EHS are discussed below.

The steps to be followed in setting priorities within the problems facing EHS through the explicit use of value judgments are similar in part to steps described under the comprehensive assessment schemes. They include:

(1) Identification and statement of environmental health problems. The stressor approach described earlier should be followed. The results of the priority setting will depend upon the efforts expended in the analysis and evaluation of the information leading to a definition of the problems. It is recommended that an effort be made to identify problems so that a working set of priorities can be established. Additional effort to define the highest ranking problems more clearly could then be undertaken.

(2) Examination and worth assessment of identified problems in terms of selection criteria (quality-of-life or other selected performance indicators)

  (a) The initial examination should identify the relevant sectors affected by or connected with the problem. The relevant sectors may include health and nonhealth factors, and some worth or value assessment may be a part of the final decision for action. Even at this step, i.e., without a complete value assessment, the bases for the decision are explicit. If factors other than health are relevant, they are identified.

  (b) Expert advice may be sought to provide the value judgments. In this case weighting factors based upon the judgments of the experts will be developed for each of the criteria. A relative value for the worth of the criteria will be established and the extent to which a given problem impacts upon a criterion, or the extent to which its solution would improve the situation, will be evaluated. This procedure could also be followed by the EHS staff if use of expert judgment is not feasible. Use of experts, however, will tend to promote more general acceptance of the results of the rating procedures.

Relevancy Matrix

Quality-of-life indices can be used in a simple way to identify the relevance of an environmental problem to each of the factors or criteria that should be considered by the decision maker. A relevancy matrix can be constructed on a totally subjective basis without any attempt to compare or assign weights to categories. Once the problems have been defined and the indicator categories selected, a relevancy matrix can be constructed. Examination of the matrix by the decision maker will reveal the categories to be considered, but he must make his own worth assessments in reaching a decision. The relevancy matrix does not in itself lead to a ranking of problems, but it can serve the decision maker as a checklist.

In Table 2 the indicator (quality of life) categories used in the illustration of the relevancy approach for several problems are presented in Table 3. A matrix can be formed of problems versus indicator category and the relevance can be indicated appropriately as shown in Table 3. Since the total environment is under scrutiny, it is likely that many problems have some relevance in all categories of indicators. The areas of major impact or most relevance can be indicated by assigning a simple worth to various levels within the category. A simple letter assignment has been made to four possible impact levels within the indicator categories shown in Table 2 in an attempt to show some significance to the decision maker. A, B, and C are simple statements of the severity of the impact and may also implicitly include the number of people affected. The distinction between C and D is that C connotes a report of a negative finding of an impact when it has been sought while D means that there is no knowledge, i. e., the impact has not even been sought. Some arbitrary worth assignments have been made for illustrative purposes for several problems relevant to EHS, and a relevancy matrix, Table 3, has been developed. By including these worth assignments in the relevancy matrix (Table 3), the decision maker can be presented a subjective view of the importance of the problem or can be made aware that a special situation exists owing to the D level.

In these examples, the focus is directed toward the problem and its impact. The impacts could be defined alternatively in terms of solutions.

Weighting by Experts

The calculation of the priority factor for each problem as it relates to environmental quality can be performed by weighting-procedures based upon the method suggested by Churchman and Ackoff.(22) The reliability and efficiency of the method has been checked in a number of instances [e.g., Reference (23)] and has been previously applied in public health decision making.(24) Weighting by experts is also the basis of the DARE technique(25) currently being explored by the Bureau of Solid Waste Management as a decision-making tool. The procedure for measuring effectiveness requires two component measures: (1) the relative value (utility) of each objective, and (2) the efficiency of each alternative or problem in achieving each objective, i. e., the probability that the selection of a particular alternative will achieve a particular objective.

Some of the critical assumptions underlying the model are:

(1) For every objective O_j, there corresponds a real nonnegative number V_j, to be interpreted as a measure of the true importance of O_j.

(2) If O_j is more important than O_k, then $V_j > V_k$, and if O_j and O_k are equally important, then $V_j = V_k$.

(3) If V_j and V_k correspond to O_j and O_k, respectively, then $V_j + V_k$ corresponds to the combined outcome O_j and O_k.

The third assumption implies that the objectives are independent and are valued individually rather than in clusters. If appropriate values are selected for the objectives and the efficiency of achieving the objectives, then the effectiveness or utility of the jth objective is $\Sigma_i e_{ij} V_j$. V_j is the estimated value of the jth objective and e_{ij} is the efficiency of the ith alternative in achieving the jth objective.

TABLE 2. IMPACT LEVELS WITHIN INDICATOR CATEGORIES

	Level
Acute Disease	
Definitely causes acute disease	A
May cause acute disease	B
Has nc relationship to acute disease	C
Lack of knowledge on relation to acute disease	D
Chronic Insults to Health	
Contributes greatly to chronic exposures	A
Some contribution to chronic exposures	B
No contribution to chronic exposures	C
Lack of knowledge on relation to chronic insults	D
Mental Illness	
Strong contributor to mental stresses	A
Some contribution to mental stress	B
No relationship to mental health	C
Lack of knowledge	D
Accidental Deaths	
Significant contributor to accidental deaths	A
May cause some accidental deaths	B
No relationship to accidental deaths	C
Lack of knowledge	D
Air Pollution	
Yields a significant amount of air pollutants	A
Contributes a limited amount of air pollutants	B
No relationship to air pollutants	C
Lack of knowledge	D
Water Pollution	
Yields a significant amount of water pollution	A
Contributes a limited amount of water pollution	B
No relationship to water pollution	C
Lack of knowledge	D

TABLE 2. (Continued)

	Level
Land Use	
Grossly inefficient use or destruction of land resource	A
Limited impact on land resource	B
No relationship to land use	C
Lack of knowledge	D
Natural (Nonrenewable) Resources	
High consumption rate of scarce resources	A
Moderate consumption rate of limited resources	B
No relationship to nonrenewable resources	C
Lack of knowledge	D
Ecosystem Structure	
Gross alteration of ecosystem structure	A
Some alteration of ecosystem structure	B
No relationship to ecosystem structure	C
Lack of knowledge	D
Population	
Substantial contribution to suboptimum population density	A
Some contribution to suboptimum population density	B
No relationship to population density	C
Lack of knowledge	D
Esthetics	
Substantial contribution to lack of beauty and character of the environment	A
Some impact on esthetics	B
No relationship to esthetics	C
No knowledge	D
Economic	
Major deterrent to economic growth or high cost to society	A
Some deterrent to economic growth or modest cost to society	B
No direct relationship to economic growth	C
Lack of knowledge	D

TABLE 3. RELEVANCE OF PROBLEMS TO ASSUMED QUALITY-OF-LIFE CATEGORIES, AN ILLUSTRATION OF THE METHOD

Problem/Indicator Category	Acute Disease	Chronic Insults to Health	Mental Illness	Accidental Deaths	Air Pollution	Water Pollution	Land Use	Natural (Nonrenewable) Resources	Ecosystem Structure	Population	Esthetics	Economics
Lead-pica[a]	A	B	A	A	C	C	C	C	C	C	C	B
Leaded gasoline[b]	C	B	D	C	B	B	C	C	C	C	C	A
DDT-body burden[c]	A	B	D	A	D	B	D	C	A	D	A	A
DDT-environmental[d]	A	B	C	A	D	A	D	C	A	D	A	A
Ultimate disposal of radioactive solid waste[e]	C	C	C	B	B	B	A	B	B	C	A	B
Noise in occupational environment[f]	C	B	C	B	C	C	C	C	C	C	C	B

(a) Elimination of lead poisoning among urban-ghetto children having pica.
(b) Reduction of body burden of lead through elimination of a major source in the environment.
(c) Reduction of body burden of DDT in the general population.
(d) Minimize impact of DDT on aquatic and avian biota.
(e) Assured long-term control of radioactive waste through ultimate disposal as solids.
(f) Elimination of deleterious impacts to man by reduction of noise levels in the occupational environment.

In applying this procedure to obtain priorities for EHS, the first step would make an initial rank ordering of the selection criteria or quality of life indices (objectives) based upon intuition. Numerical values for the criteria are then obtained. Several procedures have been described for accomplishing this(22, 24); the specific procedure depends upon the number of criteria involved. Pair-wise comparisons of the individual criteria are made, and the values assigned to the criteria are adjusted until an appropriate set of weights are obtained. Each criterion should have a weight number such that its numerical value is in proper relation to all others taken singly or in sets. The impact of the problem upon each of the criteria is then estimated by the sum defined in the preceding paragraph.

Although expert judgment can be used in the manner described above to set priorities, the credibility of the results can be improved by application of the Delphi Technique.(26-29) The Delphi Technique and several of its variants are procedures which are aimed at rectifying opinions of several experts on a particular topic into a reasonably credible "consensus". In general terms, application of the Delphi Technique requires that each expert reassess his prior statements of opinion based on feedback pertaining to the range of the prior opinions of the group of experts as a whole. This is an iterative process and is continued until a reasonable convergence of opinion or consensus occurs or until it is evident that further feedback and reassessment cycles will not lead to further resolution of divergent opinions. In strict application of the technique, experts give numerical estimates of a parameter, θ, at each cycle. The feedback to each expert is the median value and interquartile range of the distribution of values of θ produced by the group. The Delphi Technique could be employed by EHS to obtain the worth of the quality of life indices.

This technique has both desirable and undesirable attributes. Its desirable attributes include:

(1) Its workability as a useful guide to decision making in complex situations

(2) The requirement to formulate a precise unambiguous statement of the question for which opinion is being solicited, and

(3) The ability to expose and define related assumptions, hypotheses, and theories that underlie divergence opinions.

One important output of an application of the Delphi Technique consists of identifying that objective data required to corroborate a consensus or to resolve differences of opinion.

On the other hand, the results of the Delphi Technique are potentially influenced by several behavioral factors that may influence the consensus of a group of experts. These factors include the problem of group dominance in which the opinion of individual experts may be improperly swayed by the group feedback. This problem is most likely to arise where there is direct confrontation among members of the group or where an expert is relatively unsure in his opinions. Alternatively, one expert may deliberately slant his opinion excessively in one direction so as to influence the group to reach a "consensus" that he believes will support his true position.

The kinds of influences cited above have led to the development of several variants of the original Delphi Technique. In general, each variant involves some change in the feedback and reassessment procedures designed to yield greater credibility to the group consensus. Winkler(30) gives an excellent comparison of the various procedures for dealing with the "consensus problem". His comparisons are based principally on a series of experiments employing various feedback and assessment procedures. He finds that the "different methods may well produce [significantly] varying results". Essentially, he concludes that the only criterion for judging the methods is their usefulness as perceived by the decision maker: "It should be emphasized, of course, that [the decision maker] bears the responsibility for arriving at [a value of θ] and thus the choice of θ should be based on [the decision maker's] judgments, not necessarily on mechanical rules such as the methods discussed here. To the extent that such mechanical rules simplify [the decision maker's] problem and at the same time seem reasonable to him, they may be useful. After all, the theory of statistics relies heavily on rules which provide good approximations and greatly simplify the analysis. The usefulness of the methods presented here depends on the degree to which the above two requirements are satisfied."

Through either the simpler method of using expert judgment with or without the Delphi Technique, a numerical weight, w_i, would be obtained for each of the quality-of-life indices. The impact of a problem (or the worth provided by its solution), I_{ij}, within each index, i, would then be assessed by the experts. Judgment would be used to make the worth assessment and for convenience a scale of worths between 0 and 1 could be used. The priority factor P_j for each problem can then be expressed as:

$$P_j = \Sigma_i w_i I_{ij}$$

Health Potential Index

Since one of the principal foci within the mission of EHS is upon health, a simple means to determine the harm or potential harm of a problem in terms of human health has been investigated as a means to set priorities. The health potential index (HPI) incorporates into a simple product the population at risk and the severity of the effect at a single point in time, e.g., the present. The HPI is similar in concept to the urgency function described under the comprehensive method except that the rates of change with time of the severity of the effect or the number of people affected is not considered. The value of the HPI is directly related to the availability and accuracy of the input data, especially the toxicological data. If no health effects have been observed from a stressor or if the concept of a threshold dose for acute symptoms is not valid, then the HPI has little meaning. Many potentially important health effects may be missed with the HPI because missing or negative information cannot be included. Synergisms are also not included. The HPI, however, is a rapid means of evaluating the health components of environmental problems. The fact that one is forced to state the potential explicitly is a step toward rigorous and defensible priority setting.

The health potential index is based upon the assumption that the chronic exposure to a stressor can be expressed as the ratio of the body burden of the stressor (in concentration units) to the threshold body burden (in concentration units) at which acute effects are observed. The weighting factor for the acute effect is arbitrarily defined as unity; chronic effects are by definition less than unity. The health potential index is a combination of the population at risk and the severity index. Separation of the population into two groups based upon body burdens should be done in a reasonable manner for each stressor. As defined the HPI represents the current status. To provide further information to the decision maker, the health index should be followed by a plus if in the judgment of the expert the index will increase with time over the planning horizon, and minus if it is decreasing, or zero if no change is expected. The health potential index for a stressor, s, is defined as

$$HPI_s = (N_a\, S_a)_s + \Sigma_j\, (N_{C_j}\, S_{C_j})_s \quad ,$$

where

N_a = number of people exhibiting acute symptoms
S_a = severity indicator for acute effect = 1
N_{C_j} = number of people with body burden of the stressor at concentration C_j
S_{C_j} = severity indicator at body burden $C_j = \dfrac{C_j}{C_{\text{threshold, acute}}}$.

Since much of the health index rationale is based upon the principles of toxicology, the health index has been applied to the specific stressor DDT which was used as one of the test cases. A critical determination of the threshold dose for chronic exposure to DDT has not been ascertained for man. It is generally agreed that a single dose of 10 mg/kg will produce clinical symptoms in "some but not all subjects"(31). Since responses to toxicants are all or none, it should be recognized that the dose-response relationship can be described only for a population and not for an individual. At the threshold dose, the uncertainty is very high because the likelihood of a response is very small. The threshold dose can be defined only at a specific level of response in the population; e.g., 0.1, 1, or 2 percent of the population responding to that dose. There are no data for continuous exposure, but an estimate of the chronic threshold dose is likely to be 2.5 to 5 mg/kg/day(31). Such an estimate is based upon animal experiments and is likely to be high since the duration of the experiment was short in relation to the lifetime of the animals. A value of 2.5 mg/kg/day was selected as the threshold dose and a 70-kg man has been assumed for all calculations.

The body burden of the general population of the U. S. can be estimated from the surveys of DDT and chlorinated hydrocarbon residues in body fat(32-35). These data are set out in Table 4. The data are reported as the percent of the population having a given range of DDT concentration.

Durham(36) and Bailey(37) have presented a relationship between the dietary intake in terms of daily dose and the anticipated equilibrium body-fat residues. Using this expression, the estimated daily dose is calculated in Table 4 also.

Using the percent of the population having a given residue of DDT in its body fat and the population of the U. S. for that year, one can calculate the number of people exposed to that risk (Table 5). The number of people acutely exposed is more difficult to estimate. On the whole, the total number of people involved in accidental poisoning has not increased during the past 10 years (see Volume IV. Pesticides Model Case Study). The total number of reported poisonings has been held constant at about 5,000 to 6,000 per year(38). Most of the poisoning has been due to insecticides other than chlorinated hydrocarbon insecticides, which accounted for only about 10 percent. The number of persons acutely exposed, then, is about 500.

TABLE 4. LEVEL OF DDT IN THE BODY FAT OF THE GENERAL POPULATION AND THE CALCULATED DAILY INTAKE

Residue Level in Body Fat, ppm DDT	Percent of the Population Having the Given Residue[a] 1951	1956	1958	1963	Mean Calculated Daily Intake[b], mg/kg/day x 10^3
0	20	0	3	1	0.0214
0.1 to 1	9	0	0	20	0.0929
1.0 to 5	28	25	69	65	0.867
5.0 to 10	28	61	25	13	3.10
10.0 to 20	12	14	3	1	8.95
>20	3	0	0	0	13.3

(a) Reference 32.
(b) References 36 and 37.

TABLE 5. CALCULATION OF THE HEALTH INDEX FOR DDT AS A STRESSOR OF THE GENERAL POPULATION

Year	N_{total}	N_a'	$N_{0-0.1}$	$N_{0.1-1}$	N_{1-5}	N_{5-10}	N_{10-20}	$N_{>20}$
1951[a]	1.50×10^8	500	3.01×10^7	1.36×10^7	4.22×10^7	4.22×10^7	1.81×10^7	4.52×10^6
1956[a]	1.68×10^8	500	0	0	4.19×10^7	1.025×10^8	2.35×10^7	0
1958[a]	1.74×10^8	500	5.21×10^6	0	1.198×10^8	4.34×10^7	5.21×10^6	0
1963[a]	1.89×10^8	500	1.894×10^6	3.79×10^7	1.232×10^8	2.46×10^7	1.89×10^6	0
1968[a]	2.01×10^8	500	2.012×10^6	4.03×10^7	1.307×10^8	2.62×10^7	2.012×10^6	0
1973[b]	2.12×10^8	500	2.115×10^6	4.23×10^7	1.374×10^8	2.75×10^7	2.115×10^6	0
1978[b]	2.22×10^8	500	2.223×10^6	4.45×10^7	1.445×10^8	2.89×10^7	2.223×10^6	0
		S_a	$S_{0-0.1}$	$S_{0.1-1}$	S_{1-5}	S_{5-10}	S_{10-20}	$S_{>20}$
		1	8.56×10^{-6}	3.72×10^{-5}	3.47×10^{-4}	1.24×10^{-3}	3.58×10^{-3}	5.32×10^{-3}

(a) U. S. Population obtained from Statistical Abstracts U. S.
(b) Assumed 1 percent growth per year since 1968.

The health index computed for the years 1951-1978 is shown in Table 6. The index is highly insensitive to the numbers of persons acutely exposed. The weighing factor of 1 assigned to S_a probably is too low. A better methodology for the assignment of the weighing factors obviously needs to be developed. The health index is a better indicator of the tendency of the population to reach a threshold dose than of the acutely exposed. The health index suggests that if present trends were to continue, the hazard from DDT, at least, would decrease. Whether the decrease in the health index is significant cannot be predicted at present without further study.

The health potential index as defined above offers a simple means to rate stressors that includes consideration of both acute and chronic exposures. An alternative method for establishing priorities has recently been described by Hosey(39). Five indices, population (PI), relative toxicity (RT), incidence (II), quantity (QI), and trend (TI), are combined to give an overall rating for each agent. Weights from 0 to 9 are assigned to each index and the overall rating is given by: (2PI + 2RT + II + QI + TI)/5. This rating method has been applied to over 180 chemical and physical agents.

TABLE 6. HEALTH INDEX, GENERAL POPULATION

Year	N_aS_a	$N_{0-0.1}S_{0-0.1}$	$N_{0.1}S_{0.1}$	$N_{1-5}S_{1-5}$	$N_{5-10}S_{5-10}$	$N_{10-20}S_{10-20}$	$N_{>20}S_{>20}$	Health Index $\Sigma NS \times 10^4$
1951	500	2.51×10^2	5.03×10^2	1.47×10^4	5.24×10^4	6.48×10^4	2.40×10^4	15.7
1956	500	0	0	1.46×10^4	1.27×10^5	9.06×10^4	0	23.2
1958	500	4.46×10^2	0	4.16×10^4	5.38×10^4	1.87×10^4	0	11.5
1963	500	1.62×10^2	1.41×10^3	4.28×10^4	3.05×10^4	6.78×10^3	0	8.2
1968	500	1.72×10^2	1.50×10^3	4.54×10^4	3.24×10^4	7.20×10^3	0	8.7
1973	500	1.81×10^2	1.57×10^3	4.77×10^4	3.41×10^4	7.57×10^3	0	9.1
1978	500	1.91×10^2	1.66×10^3	5.02×10^4	3.59×10^4	7.96×10^3	0	9.6

R&D PLANNING

Introduction

In the preceding section of the report, systematic procedures have been described to identify the key problems and alternative courses of action open to EHS. It is recognized that completion of the initial ranking of alternatives and stressors will require a period of time, perhaps several years, and that implementation of a R&D planning system based upon stressors will require additional time. During these periods of time the R&D program planning efforts based upon the problem area and program category approach now in use by EHS will continue. To sharpen the decision-making process within EHS, it is recommended that an explicit rating procedure for projects under consideration by the planners be implemented. The particular system would preserve many of the same concepts and elements as proposed for the priority system described earlier, and it would focus attention on the problem area-program-project chain within the stated objectives at a given organizational level.

Before describing the proposed interim project rating system it is important to realize that such rating procedures do not entirely eliminate subjectivity from the program planning process. The procedure forms explicit identification and formulation of the subjective elements and achieves consistency in evaluating alternative projects. The procedures do not, in themselves, simplify the tasks of generating a set of alternative projects to be rated or of estimating probable project consequences. A primary benefit of a rating procedure is that it explicitly identifies and relates the several major tasks in program planning and delineates an operational mechanism for allocating program resources to projects in an optimal time ordered sequence.

The specific purpose of R&D planning within EHS is to provide a basis for the allocation of limited resources among alternative projects in an optimal manner to accomplish the mission of the organization. A systematic approach to the development of R&D plans focuses attention on the following:

> Objectives: The goals to be achieved or the problems for which solutions are sought. In the program planning activity, the broad, "high level" objectives of EHS must be decomposed into a hierarchy of successively more specific subobjectives to which specific projects can be related at the Administration, Bureau, Office, Division, Branch, and Section levels of the organization.
>
> Alternatives: The list of actions that can be taken to obtain the objectives.
>
> Information Base: The data package that describes each alternative and the boundaries within which the decision maker operates. In the case of EHS, the information base includes the pollution chain diagrams for a given environmental stressor, i.e., the qualitative relationships between the sources of the stressor in the environment, the physical and biological transport paths, the receptors, and the effects of the stressor upon man. The information may be simple or complex, certain or uncertain, deterministic or probablistic, clear or unclear, adequate or woefully lacking. Decisions can be made with no information, but this is not the purpose of the formalized process.

Constraints: Exogenous factors outside of the direct control of the decision maker which limit the availability of resources. Usually, there are certain constraints on action which must be met regardless of the achievement of the objectives. Enabling or authorizing legislation often states the constraints for the EHS decision makers.

Predictions of Outcomes: An analysis of each of the alternatives in the context of the working model of the system to predict the outcome of an action. The rigor of the analysis depends upon the information available. The mathematical models described elsewhere in this report serve as the tools of these predictive analyses.

Performance Measures: Measures, required for decisions, of the attainment of objectives, of the relationship to constraints, and of the available information. In many cases, the metrics are ill-defined and the performance measures are uncertain; therefore, the decision is often based to a large degree on the judgment of the decision maker. The initial system described for EHS employs extensive use of judgments. The ultimate goal is to achieve a planning system which minimizes strictly subjective inputs and provides quantitative measures of performance of the listed alternatives to the decision maker.

Project Evaluation

Project evaluation within EHS begins with the subdivision of the R&D effort into programs, each with its well-defined objectives, designed to meet specific needs. The programs are further divided into tasks with concomitant definition of task objectives. Alternative actions are identified within the tasks and specific projects are defined. These projects are then evaluated against the task objectives. At present, we are concerned with two major items:

(1) The elements that must be considered in the evaluation

(2) The procedure that will be used in establishing the project selection.

The elements to be considered depend upon the specific technology involved, the performance criteria, and the classification of the measurements. The selection process concentrates on the performance of the alternative, the risk, the cost, and the local environment.

Performance Factors

The measurement of performance is the effectiveness of an alternative to achieve a specified objective. There are two general types of performance factors - quantifiable and subjective.

To illustrate the distinction between these two classifications, consider two events from the field of sports - the decathlon and competitive diving. The decathlon is subdivided into ten events. The performance of a competitor in each event is measured in terms of specific physical quantities – time and distance. The competitive diving event is also subdivided into a specified number of dives by each competitor. The performance of the diver is dependent on a number of factors, but the evaluation is made by judges who arrive at their respective score on the basis of their subjective judgment of each dive.

In a technology where performance can be measured according to known physical laws, the quantifiable factors will be expressed in terms of the physical parameters and each alternative will be scored according to its performance. For the subjective factors, the planning process concentrates on the listing and defining of the items to be considered, e.g., in the case of the diver – approach, takeoff, air maneuver, water-entry, etc.

The relative worth of each performance factor (both quantitative and subjective) is also to be considered in the elements of evaluation. In the case of the decathlon there are pre-established points for each subevent and in the case of competitive diving there are values related to the degree of difficulty of the dive.

Risk

Two factors are considered in the risk – the probability of success and the probability of implementation. The probability of success is an estimate of the likelihood of achieving a specific objective at the stated cost. The probability of implementation is the estimate that the results will be put to use for a reasonable period of time.

Costs

Again two factors are considered in the cost – a measure of the cost of doing the R&D project and a measure of the cost of implementing the results of the R&D. The cost of doing the R&D has a dual role. It will enter into the performance-cost score, it will also be a constraint in overall program planning based on a fixed amount of resources.

Local Environmental Factors

These are factors – external to the needs and objectives of the R&D program – imposed by the inherent characteristics of the agency and its desires for survival. They are based on broad goals and personalities of people of influence. The factors are, in general, subjective factors, and their definition and measurements are based on judgment values, usually imposed by the top echelon of management. In the case of EHS, some of the local environmental factors may also be imposed by enabling legislation such as the Clean Air Act and the Solid Wastes Act.

Procedures

The purpose of a system designed for project selection or program planning is to combine these elements in a logically defensible manner. Consequently, the design of the system involves the development of procedures to accomplish this end. The main items to be developed must include the following.

(a) Data Packages. Each project in the inventory of R&D projects must be designed as specifically as possible. Thus, the establishment of the contents and format of the "data package" for each project is the first item of business. The information to be considered will depend upon the technology involved, the needs and objectives, and the availability of specific data. The usefulness of a model for program selection depends to a large extent upon the input data.

(b) Definitions. The performance factors should be specified in rigorous language. Unambiguous definitions are essential if the system model is to be operated automatically or by general analysts. The establishment of mutually exclusive objectives, precise criteria, well defined measures, and clear specifications form the basis of system operations.

(c) Measurements. Procedures for obtaining the evaluation measures are dependent upon technology and criteria. The main effort is to obtain as large a list of common measures as possible among the projects in the inventory.

(d) Weights. The relative importance of the performance factors is established prior to the use of the model. However, these weights should be determined only after a logical analysis of the factors has been made. Furthermore, since the evaluation system should be dynamic, provisions should be made for possible variations or changes in the weights.

(e) Format. The design of the system will include the format to be used in the evaluation. A well defined format will enhance the utility of the model.

(f) Algorithms. The manner in which all the factors are combined should be based on mathematical logic to insure internal consistency. The mathematics need not be sophisticated; but in comparing projects we must guard against dominating values, erroneous scaling, and obvious inconsistencies. Algorithms can also be derived for obtaining the values of measurement and sensitivity analyses.

The elements and procedures are summarized in a flow diagram shown in Figure 2.

Application to EHS

The interim project evaluation system recommended for EHS consists of the development of a performance-cost score or a figure of merit for each project. In general, this performance index, PI, for a given project, p, can be defined as

$$(\mathrm{PI})_p = \frac{[M_p] \times [P]}{C} \times B \quad ,$$

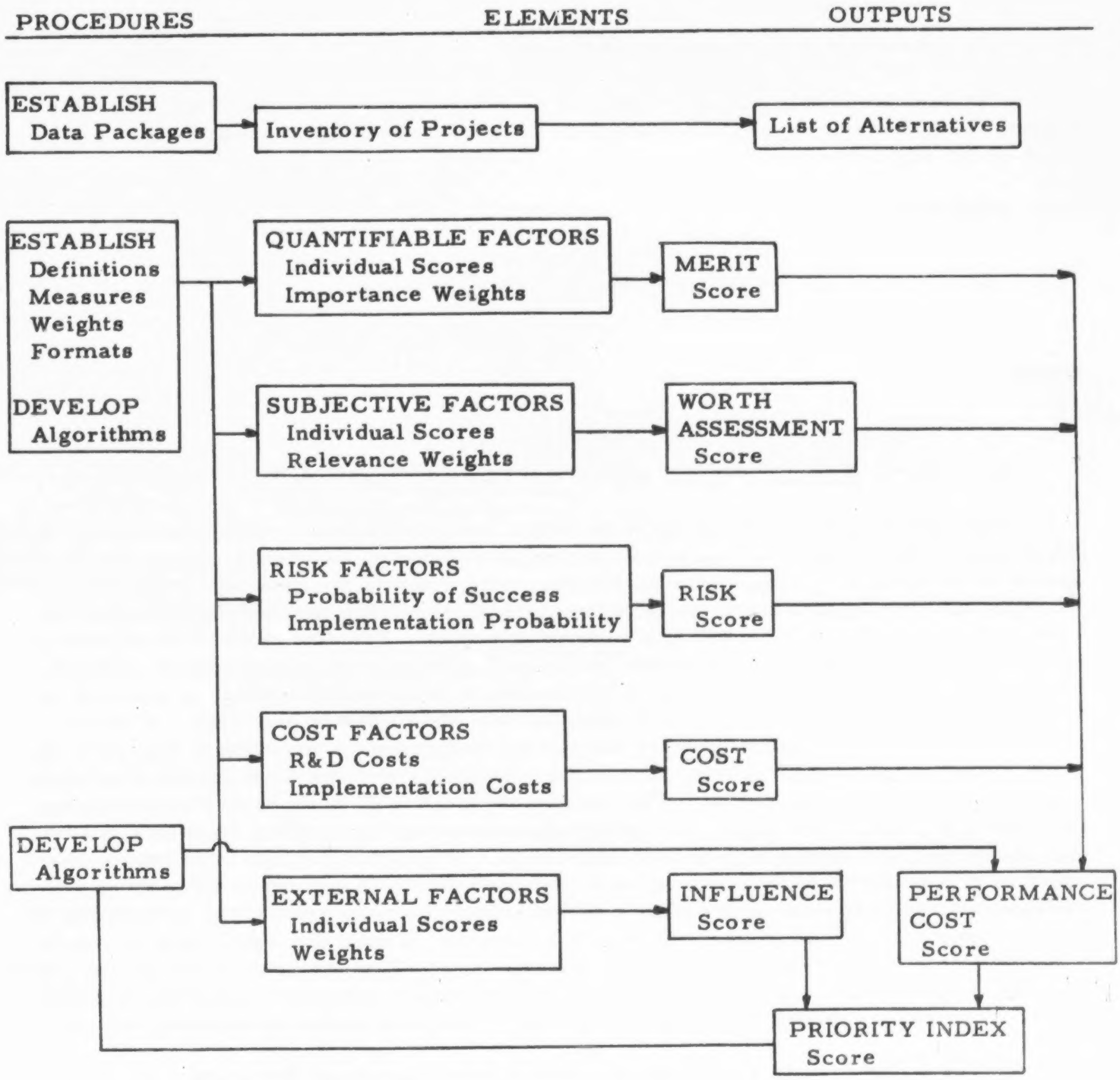
PROCEDURES
ELEMENTS
OUTPUTS
ESTABLISH Data Packages
Inventory of Projects
List of Alternatives
ESTABLISH Definitions Measures Weights Formats
DEVELOP Algorithms
QUANTIFIABLE FACTORS Individual Scores Importance Weights
MERIT Score
SUBJECTIVE FACTORS Individual Scores Relevance Weights
WORTH ASSESSMENT Score
RISK FACTORS Probability of Success Implementation Probability
RISK Score
COST FACTORS R&D Costs Implementation Costs
COST Score
DEVELOP Algorithms
EXTERNAL FACTORS Individual Scores Weights
INFLUENCE Score
PERFORMANCE COST Score
PRIORITY INDEX Score

FIGURE 2. R&D PROJECTS EVALUATION

where

M_p = factor of merit with respect to objectives

P = risk factor or probability of success

C = cost of the project

B = constraints or boundary conditions.

The factor of merit, M_p, is obtained by summing the products of the weights assigned to a given objective and the worth of the particular project toward accomplishment of the objective.

Mathematically,

$$M_p = \sum_{i=1}^{n} w_i E_{ij} \quad ,$$

where

w_i = weight number of the ith objective

E_{ij} = worth of the jth project with respect to the ith objective.

The risk or probability of success factor involved several considerations and is most conveniently expressed as a fraction between 0 and 1. It should reflect the probability of being able to complete a particular project within the time and costs allowed. This probability depends upon the existing state of knowledge and understanding of the area under consideration with respect to the objective. For example, if the objective is to remove and repaint urban/ghetto housing to eliminate lead poisoning in children having pica, current understanding of techniques to remove and repaint is high and in turn the probability of success based upon current knowledge is also high. If on the other hand the objective is to predict the effects to humans of the chronic exposure to lead, technical knowledge is limited and the probability to form an accurate prediction in a short period of time is low. The risk or probability of success in R&D projects involves availability of trained, competent manpower and laboratory facilities in addition to the current status of technical knowledge. If the R&D project is to lead to the solution of a problem in the environment, the probability of implementation must also be considered. It is obvious that there is no quantitative way to predict the probability of success of a given project; but, subjective estimates, if they are based upon thoughful considerations of experts in the field, are often valid. The use of such subjective inputs by EHS to the PI-factor are recommended for use until a quantitative system is developed. Even though the estimates are subjective, they are useful as planning indices.

The cost factor, C, should be provided by the proposer of the project and evaluated to determine if it is realistic. Unless the costs of all of the projects under consideration are of the same magnitude, a scale of costs is necessary to eliminate any obvious dominance.

The procedures for establishing weights among the objectives for a given task are the same as those previously described for the ranking and scoring of the quality of life indices. For the evaluation of projects it seems reasonable to assume that the ranking of objectives and the determination of their weights could be done by EHS personnel, at the Bureau level or below on a basis consistent with the ordering and ranking of the quality of life indices done by experts. This would be the most efficient means to accomplish the evaluation because the EHS staff would already be aware of the overall program requirements and of where a particular task fit into them. Expert opinion from the outside could also be employed for both the weight and worth assessments.

Under the lead case study, an evaluation of this interim project evaluation has been made by the project staff. Although the examples apply to the stressor connotations, individual project evaluations are the same whether a problem area program or the stressor context is used. The results of the evaluations are summarized in Table 7 to illustrate the types of results that can be obtained. Details on the specific steps that were followed and on the data inputs are given in Volume III. It should be pointed out that these results are given only to illustrate the technique being proposed. They reflect the views and biases of the project staff and do not necessarily represent the intentions of the agency.

TABLE 7. PROJECT EVALUATION FOR LEAD CASE STUDY

Objective Weights	
Objective[a]	Weight
1. Eliminate lead poisoning in urban ghetto children having pica	480
2. Minimize body burden of lead in the general population	96
3. Determine the effects of chronic lead exposure	48
4. Minimize and control occupational exposure	16
5. Identify population groups sensitive to lead exposure	4
6. Eliminate lead from bootleg liquor	1
Project Indicators	
Project[b]	PI
1. Establish laboratory program to develop more economical methods to repaint walls	0.21
2. Establish laboratories for lead screening operations for children	0.03
3. Establish allowable levels of lead in gasoline	0.07
4. Establish allowable levels of lead in automobile exhaust	0.07
5. Establish methods to determine synergistic effects	0.01
6. Establish program to document the lead epidemiology of selected communities	0.04

(a) Objectives from Table 19 in R&D project planning section in Volume III.

(b) These projects are several arbitrarily selected from Table 22 in R&D project planning section in Volume III.

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CHAPTER 3

EHS MANAGEMENT ASSISTANCE SYSTEM

INTRODUCTION

The various methods for priority setting and R&D program planning that could be used throughout the EHS organization were discussed in Chapter 2. The information network required to support these activities is described in Volume II of this report. In this chapter, attention is directed toward the management functions performed at the Service level in connection with the EHS R&D programs and to elements of a system to assist in the performance of these functions. The general philosophy upon which the discussion is based is that EHS should provide guidance to the lower organizations and remain cognizant of their activities. Facilities and capabilities within the components should not be duplicated at the Service level. Program plans should be reviewed by the Service level to assure conformity to mission requirements but the detailed planning should be performed at lower levels within the components in a coordinated manner consistent with a comprehensive plan evolved at the Service level.

There are many functions to be performed by EHS relevant to R&D program planning and management. As a result of this study there are three broad functions which should be initiated and maintained at the Service level to accomplish the R&D planning and priority activities as described in Chapter 2. These are overview environmental health planning, impact assessments, and threat identification and evaluation. Each of these functions are interrelated and each require input and participation from the components of EHS. The objectives and the activities to be pursued are described below and some estimates of the schedules, levels of effort, and possible means of implementation are made. These functions serve as the capping elements of the management assistance system for EHS.

OVERVIEW ENVIRONMENTAL HEALTH PLANNING

The objective of the overview environmental health planning (OEHP) function is to provide coordinated and comprehensive R&D planning in the man-centered ecosystem context. OEHP represents a series of steps undertaken at the Service level with the assistance and support of the components of EHS and outside contractors which will lead to the comprehensive R&D planning and priority system described in Chapter 2. A number of tools and data packages must be developed before the comprehensive system can become fully operational and these items can be developed by EHS while categorical planning is being done by the components. The current status of the tools and data packages at each point in time during the development will serve EHS as the perspective for review and coordination of the plans of the components. As the comprehensive planning system reaches full implementation, OEHP is reduced to the maintenance of the current problem statements, addition of new ones, problem area assignments, and the review of the plans developed by the components.

The activities to be performed as a part of OEHP are:

(1) Development of problem statements. The problem statements will be developed from the existing information base within the environmental stressor context to provide a systematic approach to the man-centered ecosystem context. The initial list of problem statements will be developed from state-of-the-art reports, previous and current planning efforts within the components of EHS, proposals, EHS staff expertise, etc. After an initial list of problem statements has been developed, a minimal effort will be required on a continuing basis to maintain the list through appropriate additions, corrections, and deletions. Outside contractor assistance would be recommended for the development of the initial list of problem statements.

(2) Stressor matrix input. The data extracted from the information base during the development of problem statements should be stored within the stressor matrix. This data within the matrix will be used in the R&D planning activities under OEHP and in the impact assessment and threat evaluation functions. The data stored in the stressor matrix must be readily accessible to groups participating in the planning efforts. The stressor matrix could be maintained by a contractor through the establishment of an appropriate center of competence or within EHS itself.

(3) Decision criteria. Concensus must be achieved within EHS and experts in the environmental health field on the decision criteria or quality of life indicators to be used for priority setting. The example list suggested in Chapter 2 could be expanded through analysis and evaluation of existing information, through discussions within the EHS organization, and through the conduct of symposia on the topic. This list should be developed by the EHS staff with possible assistance of an outside contractor.

(4) Relevancy matrix. After the initial lists of problem statements and decision criteria have been developed, a relevancy matrix should be assembled to provide perspective for the EHS decision makers. This activity could be performed by the EHS staff.

(5) Establish weights of decision criteria. In Chapter 2 it was recommended that Delphi techniques be employed to obtain weights for the decision criteria or quality of life indicators. This activity should be conducted by an outside contractor with close monitoring by EHS. The guidance by EHS in the selection of panels of experts will be especially important. The ranking and relative weights of the decision criteria are needed for the scoring of problem areas to determine their priorities. Use of expert judgements through Delphi techniques to establish the weights is needed until a comparable set of metrics can be developed for the quality of life indicators which is one of the activities of the impact assessment function described below. The weights for the decision criteria should be

reviewed annually by EHS and a new set of weights should be established if significant changes within the categories have occurred due to unanticipated events or actions within man's environment.

(6) Rank ordering of problems. A panel of experts, EHS staff, and/or outside contractor assistance should apply the weighted decision criteria against the initial inventory of problems and estimate the impact of the problem within each category. The weighted sums of the impacts that have been described earlier in this report should be obtained for each problem area and ranked to give a list of priorities. The ranking of problems should be reviewed annually and the additions, deletions or other modifications to the list should be made. The maintenance of the priority list and updating could be performed by the EHS staff.

(7) Problem assignments. Selection of the highest priority problems should be made by the EHS staff consistent with planning guidance received from DHEW. Problems or subproblems should be assigned by EHS to the appropriate components of the organization for detailed R&D planning. Present categorical planning within the components based upon program areas will continue until this stressor-based orientation to planning can be implemented. A minimal transitional period of time to the stressor-based approach would be anticipated since the components are likely to be pursuing the key problems based upon competent staff judgements. The stressor-based approach will reinforce their decisions and will, in addition, provide a method to assure that no critical areas are being overlooked.

(8) Review of plans by EHS. Review of the detailed R&D program plans of the components by EHS is an important activity of the OEHP. It should be done to provide a balance of effort and a coordinated approach to the man-centered ecosystem concept, and to eliminate unnecessary duplication of effort within separate components. Proper phasing of projects can be seen by EHS through a review at the Service level. Solutions to a problem in one category that may give rise to future problems in another category can be detected and the issues resolved at an early stage. Review of the detailed plans by EHS can also provide the interface for interagency coordination. The problems of implementation of a national policy for the environment have been described in a concise manner by Dreyfus[*]. A listing of classes of activities of particular concern to EHS from his preliminary compilation of agencies which administer programs within the scope of environmental management is presented in Table 8 as an indication of the

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[*] Dreyfus, D. A., "A Definition of the Scope of Environmental Management", Committee Print prepared at the request of Henry M. Jackson, Chairman, Committee on Interior and Insular Affairs, United States Senate, 1970.

The necessity for interagency coordination has also been underscored by Community Health, Inc. In their document, "Planning the Healthy Environment", excerpts of which were quoted in the Environmental Health Letter, May 1, 1970, they conclude that "although it would be inappropriate for a comprehensive health planning agency to assume that it could plan for the environmental health programs, such agencies should make efforts to become involved in the health aspects of environmental planning. This implies – and rightly so – that there are measurable health consequences of decisions made in the planning process of a variety of agencies that are not primarily health oriented. The comprehensive health planning agency is in an excellent position to identify environmental areas where a health input would be valuable and to develop the cooperative relationships necessary to secure such an input".

TABLE 8. EXCERPTS FROM A "PRELIMINARY COMPILATION OF AGENCIES WHICH ADMINISTER PROGRAMS WITHIN THE SCOPE OF ENVIRONMENTAL MANAGEMENT"[(a)]

III. ENVIRONMENTAL HEALTH AND WELL-BEING

	Implications
A. Physiological health and well-being:	
1. Sanitation:	
(a) Federal Water Pollution Control Administration, Department of Interior	1, 3
(b) Public Health Service, Health, Education, and Welfare	1
(c) Environmental Science Services Administration, Department of Commerce	1
2. Radiation control:	
(a) Federal Radiation Council	1
(b) Atomic Energy Commission	1, 3
(c) International Organizations and Conferences, Department of State	2
(d) Public Health Service, Health, Education, and Welfare	1, 3
(e) Office of Civil Defense, Department of Defense	2
3. Industrial and domestic health and safety:	
(a) U.S. Coast Guard, Department of Transportation	1
(b) Bureau of Mines, Department of Interior	1, 3
(c) Public Health Service, Health, Education, and Welfare	2, 3
(d) Farmers Home Administration, Department of Agriculture	1
(e) Consumer and Marketing Service, Department of Agriculture	2
4. Environmental health protection:	
(a) Federal Water Pollution Control Administration, Department of Interior	3
(b) Public Health Service, Health, Education, and Welfare	1, 3
(c) Office of Civil Defense, Department of Defense	2
5. Contagious disease control:	
(a) Public Health Service, Health, Education, and Welfare	2, 3
6. Pest control:	
(a) Bureau of Sport Fisheries and Wildlife, Department of Interior	1, 3
(b) Agricultural Research Service, Department of Agriculture	1

TABLE 8. (Continued)

III. ENVIRONMENTAL HEALTH AND WELL-BEING	Implications
7. Food and drug regulation:	
(a) Bureau of Narcotics, Treasury Department	2
(b) Food and Drug Administration, Health, Education, and Welfare	1, 3
(c) Consumer and Marketing Service, Department of Agriculture	1
8. Flood control:	
(a) Tennessee Valley Authority	1
(b) Bureau of Reclamation, Department of Interior	1, 3
(c) Corps of Engineers, Department of Defense	1, 3
(d) Farmers Home Administration, Department of Agriculture	2
(e) Soil Conservation Service, Department of Agriculture	1
9. Natural disaster warning and relief:	
(a) Small Business Administration	1
(b) U.S. Coast Guard, Department of Transportation	1
(c) Bureau of Commercial Fisheries, Department of Interior	1
(d) Public Health Service, Health, Education, and Welfare	1
(e) Corps of Engineers, Department of Defense	1
(f) Environmental Science Services Administration, Department of Commerce	1
(g) Federal Crop Insurance Corporation, Department of Agriculture	1
(h) Agricultural Stabilization and Conservation Service, Department of Agriculture	1
10. Population control:	
(a) Bureau of Census, Department of Commerce	3
B. Psychological health and well-being	
1. Noise suppression:	
(a) Federal Aviation Administration, Department of Transportation	1, 3
2. Relief of acoustic, mechanical, and interpersonal tension stresses:	
(a) Federal Communications Commission	2

TABLE 8. (Continued)

III. ENVIRONMENTAL HEALTH AND WELL-BEING	Implications
(b) Federal Railroad Administration, Department of Transportation	3
(c) Federal Highway Administration, Department of Transportation	1
(d) Federal Aviation Administration, Department of Transportation	1, 3
(e) Land and Facilities Development Administration, Housing and Urban Development	1
3. Promotion of community identity:	
(a) Federal Housing Administration, Housing and Urban Development	2
(b) Office of Community Development, Housing and Urban Development	1
4. Population dispersion:	
(a) Federal Railroad Administration, Department of Transportation	1
(b) Federal Housing Administration, Housing and Urban Development	2
5. Environmental education:	
(a) Smithsonian Institution	1
(b) International Organization and Conferences, Department of State	1
(c) Office of Water Resources Research, Department of Interior	1
(d) Federal Water Pollution Control Administration, Department of Interior	1
(e) Office of Information, Department of Agriculture	1, 3

V. ECOLOGICAL RESEARCH	Implications[a]
A. Human ecology:	
1. Basic research in human ecology:	
(a) Smithsonian Institution	1
(b) National Science Foundation	1
(c) Appalachian Regional Commission	2
(d) Federal Field Committee for Development Planning in Alaska	2
(e) Federal Aeronautics and Space Administration	3

TABLE 8. (Continued)

V. ECOLOGICAL RESEARCH

		Implications[a]
(f)	Atomic Energy Commission	3
(g)	International Organization and Conferences, Department of State	3
(h)	Bureau of Labor Statistics, Department of Labor	3
(i)	Geological Survey, Department of Interior	3
(j)	Office of Territories, Department of Interior	2
(k)	Public Health Service, Health, Education, and Welfare	3
(l)	Research and Development, Department of Defense	2
(m)	National Bureau of Standards	3
(n)	Environmental Science Services Administration, Department of Commerce	3
(o)	Bureau of the Census, Department of Commerce	3

(a) The agency administers programs which have the following implications to the environmental activity:

1 = Continuous significant functions requiring control and coordination
2 = Occasional significant functions requiring surveillance
3 = Relevant data collection and research functions.

Source: Dreyfus, D. A., "A Definition of the Scope of Environmental Management", Committee on Interior and Insular Affairs, United States Senate, 1970.

importance of interagency coordination. The activities of the Council on Environmental Quality, the President's Office of Science and Technology, and the National Science Foundation are also important to EHS, but are not noted in Table 3-1. EHS should attempt to eliminate unnecessary duplication of efforts expended elsewhere in the Federal Government on man-centered ecosystem problems as well as within its own organization.

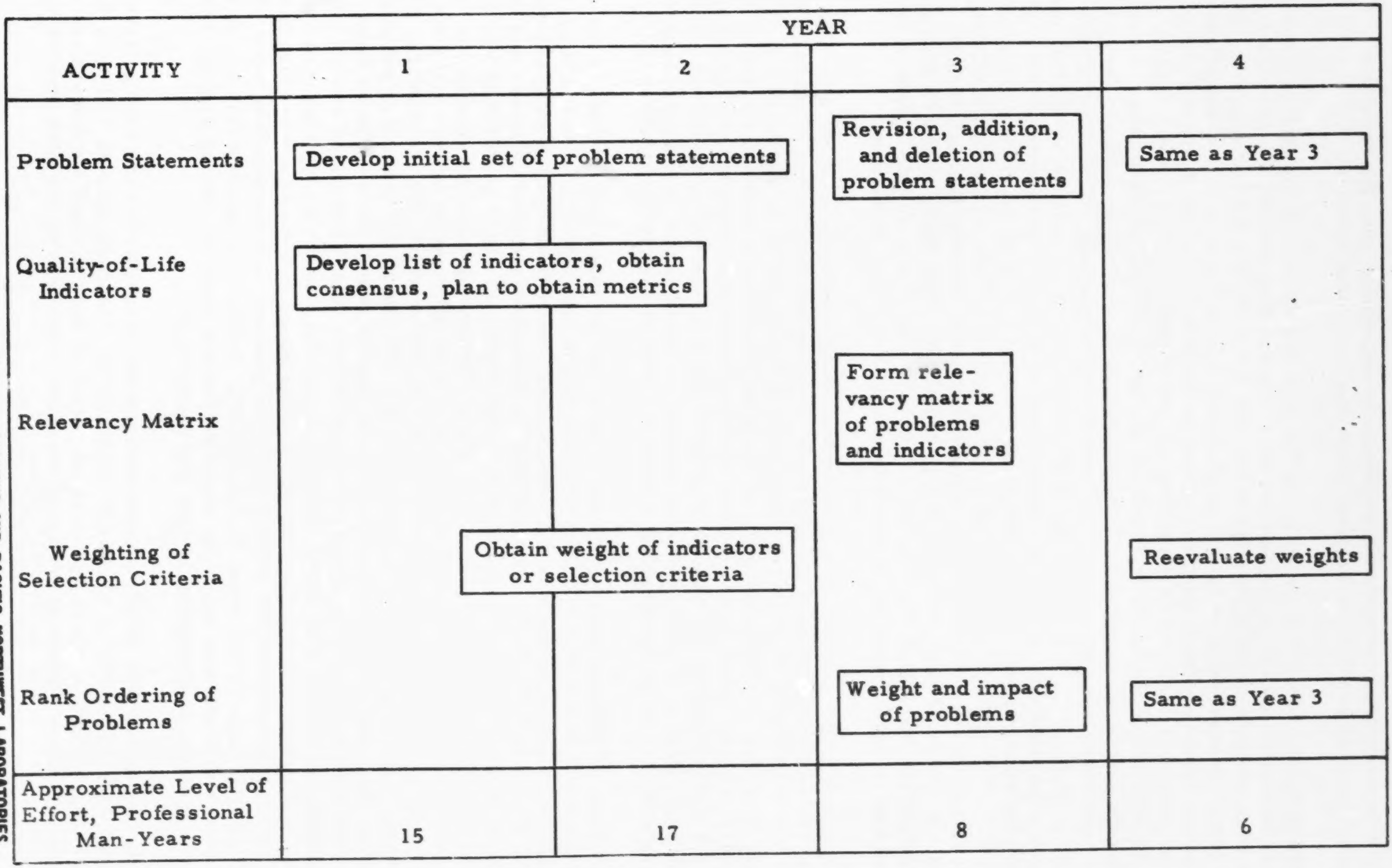
(9) Program selection. The final activity in a planning cycle is selection of the proper mix of projects to form a program. The mix is based upon priority, expected accomplishments, and cost. EHS in conjunction with the components should make this selection.

A schedule of these activities within OEHP is presented in Figure 3. An estimate of the level of effort by professional staff by year is indicated on the schedule. This activity could be conducted entirely within EHS, entirely by outside contractors, or by a combination of EHS staff and contractors. After the third year, the sole use of EHS staff is recommended. The breakdown of professional staff would be 10 senior- and 5 junior-level staff the first year, 12 senior and 5 junior level the second year, 6 senior and 2 junior level the third, and 4 senior and 2 junior level staff the fourth and succeeding years. Appropriate secretarial support is required.

IMPACT ASSESSMENT

A second important function to be performed by the management assistance system is to provide assessments to EHS of the impact of technology upon man and his environment. These assessments provide EHS management important evaluations upon which policies can be established, planning can be performed, and actions can be implemented. In principle, the scope of the assessments can range from the evaluation of the first-order impacts of technology upon a small sector of the population or the environment to broader impacts encompassing several orders of interactions with many sectors of the population and the environment. Assessments of the former type could be performed at lower organizational levels since they are most directly concerned while those of the latter type which cross categorical boundaries should be performed at the Service level. The capability to perform the broader assessments encompasses the capability to perform the narrower so the Service level would be able to perform the entire function if needed.

The impact-assessment function is not distinct from the overview-planning and threat-evaluation functions. Assessment of various types are required in the planning efforts to evaluate alternative courses of actions and to provide a measure of the urgency of a problem. Assessments of lower order interactions are also a part of the threat evaluation function and provide estimates of the detrimental impacts of a suspected environmental stressor. The impact assessment function, however, extends beyond these efforts and provides perspective to EHS management outside of the immediate planning requirements. It can provide EHS one of the major tools for framing policy. The impact assessment function can serve to guide and evaluate the activities associated with development of metrics for the quality of life indicators.



ACTIVITY	YEAR 1	YEAR 2	YEAR 3	YEAR 4
Problem Statements	Develop initial set of problem statements		Revision, addition, and deletion of problem statements	Same as Year 3
Quality-of-Life Indicators	Develop list of indicators, obtain consensus, plan to obtain metrics			
Relevancy Matrix			Form relevancy matrix of problems and indicators	
Weighting of Selection Criteria	Obtain weight of indicators or selection criteria			Reevaluate weights
Rank Ordering of Problems			Weight and impact of problems	Same as Year 3
Approximate Level of Effort, Professional Man-Years	15	17	8	6

FIGURE 3. SCHEDULE OF ACTIVITIES FOR OVERVIEW ENVIRONMENTAL HEALTH PLANNING

The broad assessment capability offers means to determine specific requirements for the metrics through sensitivity analyses involving many interactions.

The general approach to be followed by EHS to establish an impact-assessment capability will be to gather at the Service level the existing mathematical models for specific assessments which have been developed for or within the components. These models would be assembled to form a hierarchy of models for impact assessment. Modifications would be made where required to achieve compatibility among these models at the lower echelons of the hierarchy and higher echelon models would be developed to utilize the outputs from lower levels for the broad assessments. As additional models are developed within EHS components they would be added to the hierarchy and EHS may request models to be developed by its components to fill gaps in the hierarchy. An important aspect of the higher echelon models will be to provide means of analyzing the interactions between the various stressors and impacts within a broad problem area being assessed. The interaction analysis will be one of the major efforts at the Service level in the impact assessment function of EHS. As noted in Chapter 2, there is currently keen interest in technology assessment within several Federal agencies. Models and assessment methods developed under these auspices should be incorporated into the EHS hierarchy where appropriate. Through this approach the ability of EHS to perform complex assessments will increase with time.

Each step of the acquisition and assembly of the hierarchy of models by EHS should be tested through making assessments. An assessment cannot be made in the abstract and the trial or actual assessments provide a measure of performance of the model and guidance for improvement. A complex assessment problem should be attempted within the first two years after this effort has been initiated. Even though the results of the assessment will be incomplete because the hierarchy of models will not be fully developed, it will reveal the weakness and strengths of the existing system and indicate the future directions that should be taken to expand the hierarchy.

A typical broad assessment problem that might be undertaken by EHS is the assessment of the impact on man and his environment of the removal of lead in the atmosphere followed by a reduction of the body burdens of lead, the increase in the efficiencies and the useful lifetimes of catalytic recombiners in automotive exhaust systems, and the economic impacts within the lead industry. (The lead case study reported in Volume III only dealt with the first item.) Some secondary considerations might include the assessment of impact of new additives to gasoline upon man; alternative power cycles for vehicles; and the use of electrical power for automobiles which will increase the need for electrical generating capacity, change the distribution of the sources of pollution in the environment, and increase the amount of electrical power plant effluents being discharged into the environment. Some additional factors to be considered are the penalties of operating engines with lower octane fuel and the conservation of the lead ore resource. Numerous other factors should be considered in a broad assessment but this list in itself illustrates the complexity of the problem and the possible types of interactions and impacts that must be considered. Other assessments that are directly relevant to the EHS mission would be integrated waste systems, human ecology and the urban environment, and alternative pest control methods.

It is recommended that the impact assessment capability for the Service level be carried out with the assitance of outside contractors. This will provide EHS with the possibility of increasing the effort over a short period of time to meet a critical need without a long-term commitment to staff. At least one individual on the EHS staff should be actively involved with the contractor in the assessment efforts. A minimum of 2-1/2 man-years per year rate of effort on the part of the contractor should be considered initially, exclusive of efforts to develop metrics for the quality of life indicators. Approximately 1 man-year per year of computer programming support is also required.

With respect to the quality of life indicators, insufficient effort has been devoted under this project to specify a detailed plan for the development of metrics. A logical step beyond those of this project would be to perform a more thorough evaluation of existing information on indicators and suggested metrics to establish working hypotheses. These hypotheses for likely metrics could be discussed and amplified through a couple working meetings or seminars with interested experts. A detailed plan for the development of the metrics and for the evaluation of their validity should be produced from this effort.

An expansion of the concept of the impact assessment function for EHS could lead to the establishment of a center of technical competence for the continuing assessment of the impact of technology on man and his environment. There is at present no central location either within or outside the Federal Government that is continually developing methods for assessing the impact of technology on the environment and applying these methods to the assessment of recognized problems or identification of emerging problems. Such efforts are currently being conducted on an individual and often ad-hoc basis, and no one is trying to use these efforts to formulate an approach to man and his total environment. EHS could provide national leadership for the collection, development, and evaluation of predictive methods, and for the application of these methods to environmental problems. This could be done through a center of competence as described in Volume II.

The Center of Technical Competence for Assessment Technology would have as its objectives to:

(a) Collect mathematical models or methods developed to predict or analyze impact of technology on man and his environment.

(b) Assemble, integrate, or formulate a hierarchy of models to analyze particular problems (EHS requests, outside requests, internally stimulated).

(c) Perform research leading to the definition and acceptance of quality of life indices.

(d) Develop value functions to measure environmental impacts.

An active effort is required to accomplish the objectives. Collection of project listings or bibliographic data is not sufficient from a user's point of view. Application and communication of the results of the evaluation and analysis efforts is required. Unless the collectors and evaluators are users they have neither the contacts to obtain the information nor the perspective for its use.

If this center were established, it could be used by:

(1) EHS to

Assess specific problems (threats, requests from Congress, etc.)

Assist in program planning (evaluate and correlate work)

Identify needs for specific data and monitoring networks

Give visibility to its assessment of environmental impacts, document existing analytical methodology

(2) Other Governmental agencies to

Analyze pressing problems (region, city, neighborhood, specific industry)

Provide analytical competence that is not available elsewhere

(This assistance could be provided on a contract basis or through cooperative programs with EHS);

(3) Industries to

Obtain information on analytical methods

Assist in the evaluation of significant problems.

The level of effort required to establish and operate a center of technical competence would be higher than the internal EHS impact assessment function since a more concerted effort would be made to obtain models from all sources and efforts would be made to obtain users outside of EHS. A level of effort at 4 to 4-1/2 man-years of senior professional staff, 2 man-years of junior level staff, and 2 man-years per year of computer programming assistance would be a preliminary estimate and would be expanded to meet the demand placed on the center by user groups. Secretarial support would also be needed. User charges would be assessed to these groups outside of EHS to cover the increased costs of the expanded activities and a continuing support of the center by EHS would be required to provide continuity. Since this center would serve a wide user audience, operation through a contractor is recommended. If desired, if user fees could be accommodated, and if EHS staff were available for this function exclusively, the center could be set up within EHS.

THREAT IDENTIFICATION AND THREAT EVALUATION

The previously described functions of the management assistance system focus principally upon the current, recognized problems within the man-centered ecosystem. These functions would be complemented by the third function, threat identification and evaluation, which has as its focus the potential threats to man and his environment through intensification or extension of current use patterns of products and services or through the introduction of new chemical, biological, or physical stressors into the environment. Some of this function is implicit in the comprehensive planning system, but a clearly defined responsibility for threat identification and evaluation within EHS will assure that impending problems are receiving proper attention.

The need to maintain a continuous surveillance of chemical contaminants in the environment was examined in an earlier study for the Public Health Service(1)* and the elements of an early warning system for this class of environmental stressors was described. It is interesting to note that this study determined that a significant amount of mercury is discharged from various uses into the environment and that there is bioaccumulation of mercury in man's food chains. In effect, the problem of mercury contamination in fish in the Great Lakes was detectable through a threat evaluation several years previous to its detection in consumer foods. Within the man-centered ecosystem concept, threat evaluation must consider biological and physical stressors in addition to the chemical contaminants so that the concept is broader than that developed in the previous study.

Threat evaluation involves two phases, threat identification and threat assessment. The threat-identification function would be performed by a small group of individuals representing physical, chemical, and biological disciplines. It would be the purpose of this group to question trends or patterns in given industrial, urban, occupational, domestic, and recreational areas and to evaluate in a cursory manner the available information that might suggest the possibility of a threat. The EHIN described in Volume II would be used for this purpose. If a possible threat were identified, the threat evaluation mechanism described in Volume II could be set in motion by EHS. Depending upon the magnitude of the potential threat, a center of technical competence may be established.

The level of effort that would be required on a continuing basis for the threat-identification aspects of the threat evaluation function would be 3 to 5 man-years per year assuming that the EHIN were operational and that immediate access could be gained to the data base used in the OEHP and impact assessment functions. This identification function could be performed within EHS, but complementary assistance by outside contractors or consultants who may be more closely attuned to trends in the areas noted would be desirable.

ENVIRONMENTAL STRESSOR MATRIX

There are several methods that can be employed for the identification of problem areas in the environment and for developing problem statements. In the previous discussion of the usefulness of the environmental stressor approach, it was mentioned that an environmental stressor matrix can serve as a method for listing of pertinent information and for focusing attention of the planner on cause and effect relationships. A discussion of a preliminary environmental stressor matrix concept is presented in this section with an example of its applicability to the lead model case study.

An environmental stressor is defined as the environmental agent or factor of concern reduced to its simplest terms or its most fundamental unit. A listing of

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*References for this Chapter are listed on page 67.

environmental stressors compiled during this project is presented in Appendix A. More experience in collecting and storage of information in light of the environmental stressor matrix is needed to ascertain how to specify stressors. Aggregation of the stressors under the major categories into broader classes may be adequate*. In the lead case study it appears to be sufficient to treat the lead stressor under a single heading rather than divide into smaller segments by specific lead compound.

The concept of an environmental stressor matrix borrows heavily from ideas developed by Lee(2) and Isard(3). Such a systems approach using input-output techniques has also been explored in the mental health area by Hutchison and Krause(4). One of the objectives of the use of the environmental stressor concept is to trace an agent from its several sources along all of its environmental pathways through various receptors to determine its effect upon man. A matrix in which stressors are arrayed against sources, transport paths, and effects classifications is one means to accomplish this. If quantitative information can be obtained, a stressor matrix can provide much of the input needed for predictive mathematical modeling. A coordinate reference system, utilizing the class of environmental factors (stressors) and the focus of interest (sources, transport paths, and effects) as the two coordinates, was developed by Lee as a means of indexing and filing documents. This two-coordinate system appears to have utility beyond the storage and retrieval of pertinent reference material. The environmental pathways of the stressor (factor) can be traced by following the stressor across the foci of interest. By examining a single focus, the number of stressors within it can be identified, and questions of the possibilities of combined effects of the stressors can be raised. Lee's concept thus has capabilities of illustrating the relevance between stressors and foci in the environment and of the identification of possible interactions in a qualitative manner.

Isard(3) has expanded the input-output techniques used in economic analysis to include the ecologic system. The ecologic system receives various commodities as a result of economic activities. For example, the release of airborne particulates as a result of industrial processing can be treated as an export from the economic activity to the ecologic system. In turn the economic system requires certain ecologic quantities as input to its activities, e.g., quantities of water of high quality. Based upon these considerations, an accounting framework for a fused ecologic-economic system can be developed. For the purposes of the environmental stressor matrix, this accounting framework provides a basis to identify stressors with sources and to obtain a quantitative measure of the stressor output. Isard has also used the input-output framework within the ecologic system itself and has tied ecologic commodities to ecologic processes through interprocess coefficients. For some stressors, this offers the potential for developing quantitative relationships within the ecologic system.

The preliminary environmental stressor matrix which has evolved, in part from the combination of the qualitative concepts of Lee(2) and the quantitative framework of Isard(3), is illustrated in Figure 4. The breakdown under each of the columns is listed in Table 9. The environmental stressors are listed under the first column in the matrix. In the second column, sources, the amount of the stressor released to the environment from a given source is tabulated. Convenient units for the information in this column could be quantity (mass, number, decibels, etc.) per unit time or quantity per unit activity in the economic sense. The third column of the matrix, compartment,

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*Environmental stressors are analogous to the environmental factors considered by Lee.(2) He has aggregated the stressors into 30 classes.

		TRANSPORT PATH						
Stressor	Sources	Medium		Compartment	Portal of Entry	Target (Site) of Action	Population Subgroup Modifiers	Consequences
	Quantity per unit time or Quantity per unit activity	Concentration	HUMAN	Exposure per unit time	Quantity per unit activity	Concentration per unit exposure		
				Compartment	Target of Action		Group Modifier	Consequences
			BIOTA	Exposure per unit time	Concentration per unit exposure		Factor	

FIGURE 4. PRELIMINARY ENVIRONMENTAL STRESSOR MATRIX CONCEPT

TABLE 9. BREAKDOWN OF COLUMN CLASSIFICATIONS

Sources[a]

Use standard industrial classifications. Major divisions given below.

- Agriculture, Forestry, and Fisheries
- Mining
- Contract Construction
- Manufacturing
- Transportation, Communication, Electric, Gas, and Sanitary Services
- Wholesale and Retail Trade
- Finance, Insurance, and Real Estate Services

Medium[b]

- Atmosphere
- Hydrosphere
- Lithosphere
- Biota
- Humans

Compartment – Humans[b]

- Domestic
- Occupational
- Service
- Recreational
- Transportational

Portal of Entry[b]

- Skin
- Respiratory tract
- Alimentary tract
- Genito-urinary tract
- Sensory apparatus

Target (Site) of Action[b]

- Total organism
- Systems
- Organs
- Tissues
- Cells
  - Chromosomes
  - Organelles
  - Membranes

Population Subgroup Modifiers – Humans[b]

- Genetic
- Group patterns
- Individual experience
- Physiological status

Consequences – Humans

- Physiological-psychological[b]
- Longevity
- Productivity
- Metabolism
  - Reproduction
  - Normality
- Economic
- Political
- Sociological

Compartment – Biota

- Producers
- Herbivores
- Carnivores
- Detritivores

Targets of Action – Biota

- Biome

TABLE 9. (Continued)

Targets of Action – Biota (Continued)	Consequences – Biota
Ecosystem	Longevity
Community	Productivity
Population	Reproduction
Organism	Normality
Group Modifier – Biota	

(a) Standard Industrial Classification Manual, 1967, Executive Office of the President.

(b) Private communication, D. Lee.

represents an instantaneous distribution of the stressor among the media indicated. The values in this column could be expressed in terms of amount per unit volume, area, or mass appropriate to the stressor. There should be a mass balance between all of the second and third columns. At this point, it appears convenient to separate the stressor matrix into two parts, one dealing with humans and the other treating the biota. In the next column in the humans section of the matrix, portal of entry, the exposure to the stressor per unit time (and, if convenient, unit concentration) is tabulated. This column effectively partitions the exposure according to individual activities. Under the portal of entry column, data on the stressor are tabulated, by amounts, in the various pathways. The target site of action is identified, and the concentration of the stressor in the target for a given unit of exposure is tabulated. Population subgroup modifiers are factors that should be applied against sensitive population subgroups. The amplification factor and the sensitive group must be tabulated. Under the consequences column, the effects or consequences of exposure to a given stressor are presented. In the biota section of the matrix, it appears desirable to have different column headings. The compartment column would consist of the exposure per unit time to a stressor, or perhaps amount accumulated per unit mass, within the classifications of producers, consumers, and detritus. The target for the impact of the stressor are the biome, ecosystem, community, population, or organism; and if there are modifiers, they should be noted.

The environmental stressor matrix provides a framework for following the stressor through the environment, and the quantitative data will serve as input to predictive mathematical models. By inspection of the matrix, the significant sources of the stressor and principal elements along its transport path can be identified. This information in itself is useful to suggest means to minimize or eliminate the consequences of a stressor in the environment. If attention is directed to one of the columns of the matrix, the possibilities for synergistic or antagonistic effects exists. Data should be evaluated in light of these possibilities.

In using the environmental stressor matrix, it will be important to identify areas where no data exist or where an investigation has been made and the results were negative. This information is just as important for environmental health planning as the positive results. If areas where no data exist are clearly noted, critical information gaps can be identified by simple inspection of the matrix.

To illustrate the applicability of the environmental stressor matrix concept, the available data for the lead and pesticide case studies, Volumes III and IV were summarized and are presented in matrix form in Table 10. Only a single line entry for the source information was made for each of the stressors and the quantity of the stressor produced annually is indicated by the parenthesis. A more complete representation of the source information would be a two-dimensional array showing the transfers of the stressors between industries. For illustrative purposes, only a few categories under the transport paths are shown and the data are limited to humans.

Even in its preliminary form the environmental stressor matrix appears to serve as a potentially useful tool to provide assistance to EHS management. The stressor matrix concept could easily be implemented in a supportive role to the three assistance functions discussed previously. The stressor matrix could serve as a convenient and efficient means for summarizing, storing, and presenting data during the development or problem statements under the OEHP function. It likewise could provide a compact storage system for the data to be used in impact assessment and the input-output

TABLE 10. ENVIRONMENTAL STRESSOR MATRIX - PRELIMINARY

	Source (Standard Industrial Classification)								
Stressor	Agricultural Production 01	Forestry 07	Metal Mining 10	Construction, Special Trade Contractors 17	Ordnance and Accessories 19	Chemicals and Allied Products 28	Primary Metal Industries 33	Fabricated Metal Products 34	Electrical Machinery 36
					Tons				
Lead			(501, 886)(a)	112, 256	77, 805	373, 014	(1, 539, 757)(b, c)	211, 681	558, 121
DDT	16, 770(d)	3, 747(d)				(67, 897)(d)			

	Medium			Compartment			Portal of Entry		
	Air, µg/m³	Water, µg/1	Land, µg/g	Domestic, µg/m³	Occupational, µg/m³	Transportational, µg/m³	Skin, µg/day	Respiratory Tract, µg/day	Alimentary Tract, µg/day
Lead	1. 6 to 4. 0 (urban)(e)	1. 5 to 60. 0 (drinking)(f)	13. 9 to 95. 7(f)		1. 0 - 49. 0(e)	0. 1 - 3. 5 (alkyl lead)(e)	Negligible	20. 0(f)	300. 0(f)
	0. 5 (composite rural U. S.)(g)				1. 0 - 11. 0(e) (insecticides)	1. 3 - 2. 8 (inorganic)(e)			
DDT	1 x 10^{-4} (total U. S. average)	0. 02 (drinking)		0. 0005	0. 01 - 0. 04				40. 0

TABLE 10. (Continued)

	Target (Site of Action)		Consequences	
	System, µg/100 g	Tissues (Autopsy Tissue),(b) µg/100 g	Acute	Chronic
Lead	Blood 17	Bone (flat) 210-1110 Bone (long) 670, 3600 Liver 120 Kidney 50 Muscle 80 Spleen 30 Lung 20 Ash Adrenal 53 Liver 150 Aorta 160 Lungs 67 Cecum 38 Pancreas 69 Kidney 120 Trachea 58 Larynx 95	TEL penetration of skin: Insomnia, headache, restlessness, dizziness, irritability, ataxia, delusions, anemia, and sometimes convulsions Ingestion of metabolic lead: Pain, leg cramps, muscle weakness, paresthesias, depression, coma, death	Anorexia, a metallic taste, constipation and severe abdominal cramps, pallor, elevated blood pressure, wrist drop, foot drop, encephalopathy
DDT		Body Fat 2.4 - 3.7 ppm(h)	Mild cases Headaches, dizziness, gastrointestinal disturbances, numbness, and weakness of extremities, apprehension, and hyperirritability Large doses Muscular tremors, convulsions, cardiac or respiratory failure, and death	

(a) Mine production of recoverable lead in 1969.

(b) Total new supply of U. S. lead in 1969.

(c) Total consumption based on SIC categories; estimated undistributed consumption 42,300 tons. 1969 use consumption pattern gives 42,000 tons undistributed consumption (Mineral Industry Surveys. Lead Industry – Preliminary Totals for 1970, U. S. Department of Interior, Bureau of Mines.)

(d) Frear, D. E. H., "Pesticide Handbook-Entoma", Twenty-First Edition (1969), p 28 (Pesticide Usage, 1964).

(e) Symposium on Environmental Lead Contamination, December 13-15, 1965, PHS Publication No. 1440 (March, 1966).

(f) Haley, T. J., Air Quality Monograph No. 69-7, American Petroleum Institute, N. Y. (1969).

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(h) Hayes, W. J., "Monitoring Food and People for Pesticide Control", in Scientific Aspects of Pest Control, Publication 1402, National Academy of Sciences – National Research Council, Washington, D. C. (1966).

framework could be essential in the determination of material balances for stressors in the threat identification and evaluation function. The master file of information in the stressor matrix should be maintained by EHS. Initially the matrix could be maintained manually so that changes in the format of the entries can be made readily; but, as the input data became more numerous, computer handling should be considered. The components of EHS should be made aware of this matrix and appropriate input should be obtained from them. The input should be the value of interest and a reference to its original source.

MATHEMATICAL MODELING TO PREDICT THE IMPACT OF TECHNOLOGY ON THE ENVIRONMENT

In this era of technological innovation in which modern technology is usually pursued in order to provide great benefits to the quality of life, concomittent with, and as a result of, the technological benefits, are changes in the environment. These environmental changes are accelerated at the same rate as the rate of technological development. The status of the quality of life for man is highly dependent upon the various changes that are constantly occurring in the total environment. Mathematical modeling is an important tool that can be used by EHS management to determine the status of the quality of life.

The Hierarchical Approach

Definition

The hierarchical approach is an efficient method of obtaining operationally adequate simulation models for complex problems. In this approach, several echelons of modeling effort are defined such that there are several lower-echelon models of varying detail and a broad, top-echelon model. In the top-echelon model, the mathematical description of individual phenomena may be relatively unsophisticated but these descriptions are adequate for a valid comparison of the phenomena. Valid simplifications of the phenomena are sought such that the higher echelon models do not delve into unnecessary detail in a particular area. The lower-echelon models may utilize very sophisticated mathematical representations in order to describe a particular area in great detail. In modeling a relatively large and complex problem, there may be a whole spectrum of models between the highest and lowest echelons, where the top-echelon model is the big picture or major aspect of the system, lacking detail but being broad enough to incorporate all important aspects of all subsystems, while the lower-echelon models are like looking at cross-sections of the system through a microscope.

The evolution of a comprehensive model can be described by the following five steps:

(1) Review literature on the problems

(2) Form preliminary models from data in the literature and best estimates

(3) Use preliminary models to guide further data acquisition and to guide further model development

(4) Test the models with suitable validating experiments

(5) Use the validated model for the desired predictions.

The evolutionary process will usually require jumping between several levels of modeling. As an example, the top-echelon model could proceed through steps (1) and (2) at the very early stages of the model development. However, Step (3) might necessitate a more detailed examination of a particular area and this would require the development of a lower-echelon model for that area. This lower-echelon model might then proceed through the five steps of the evolutionary process in order to develop a relatively detailed model for the area under examination. If the mathematical sophistication or detail of the model is too complex for the purposes of the top-echelon model, the results of the lower-echelon model would be used to develop some simpler empirical relationships which would then be used in the top-echelon model. The evolutionary process for the top-echelon model could then proceed to the next step.

The evolutionary or development process for a hierarchical set of models is an iterative process. In this process, a hierarchy of incompletely developed models, in the preliminary development stages, is iterated to an acceptable degree of convergence or self-consistency of the hierarchy while progressive improvement and validation of the individual models in the hierarchy is performed by comparing simulation outputs with experimental data. While this iterative process improves lower-echelon models, the whole hierarchy of models improve in quality. Some of the models in a hierarchy, particularly in lower echelons, are not of major interest in themselves. They are included only because they serve to implement some portion of a higher-echelon model by the iteration process. Often it would become apparent at some stage of development that the contribution by the lower-echelon model is negligible. Then, this whole lower-echelon model can be disregarded thereafter.

Applicability to EHS

The hierarchical approach seems to lend itself extremely well to the structure and mission of EHS. The structure of EHS is organized hierarchically within the DHEW with each of the operating bureaus or offices in EHS being responsible for some part of the total EHS mission of providing man the best possible quality of life. To accomplish this mission the assessment of the status of the quality of life must be ultimately performed. This assessment is dependent upon the "total costs-total benefit" ratio predictions generated for all stressors by each bureau and office in EHS. The implication of "total costs" and "total benefits" includes a wide spectrum of costs-benefits beyond only economic ones. Therefore, developing an approach to provide EHS with a tool to systematically investigate the impact of all stressors upon man within the total environment encompasses a predictive model which is hierarchical in nature.

At the top echelon of this hierarchy of models should be EHS, because EHS must make program decisions based upon input from lower-echelon models. Two major hierarchical structures are at a lower level than EHS. One is the organizational components of EHS. The other hierarchical structure is the hierarchical set of models which contribute to the determination of the status of the quality of life. A schematic representation of the hierarchy of models applicable to EHS is shown in Figure 5. Each of the lower-echelon models in the hierarchical model for the quality of life may

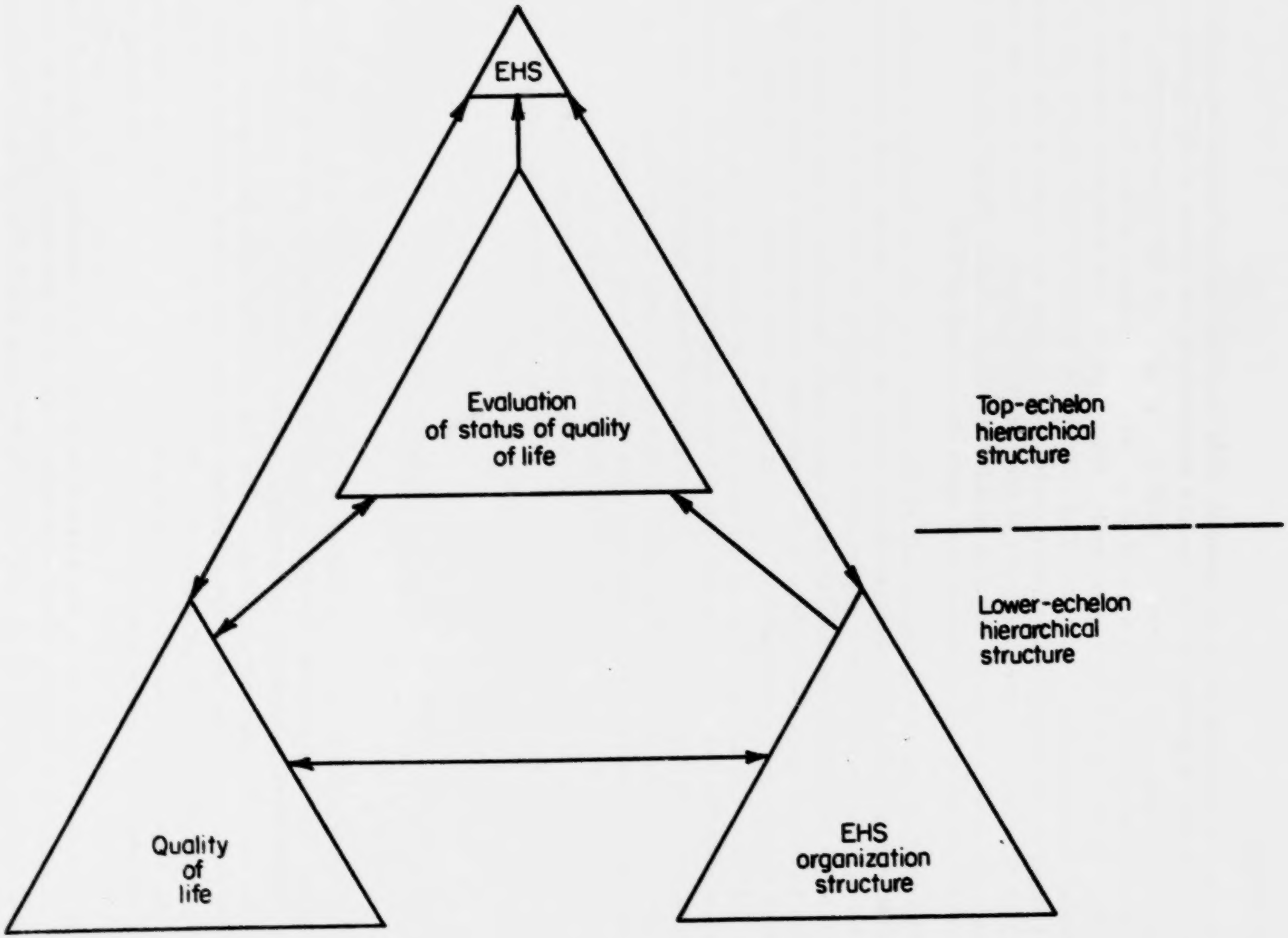
EHS
Evaluation of status of quality of life
Top-echelon hierarchical structure
Lower-echelon hierarchical structure
Quality of life
EHS organization structure

FIGURE 5. THE EHS HIERARCHY OF MODELS

also be hierarchical in nature, e.g., the environmental stressor hierarchy may include groups and types of stressors and the transport pathways hierarchy includes several environmental pathways.

Typical Output

At the top echelon of these models, EHS can maintain hierarchical control of the models. The set of quality of life models determines the status of the quality of life as an output which may then be used as input to EHS or the EHS organizational components. There is coupling between the sets of lower-echelon models within the quality of life hierarchy. In the lead model case study, for example, the transport pathway and the body model were coupled together. The calculated values of lead source emission were used as input to the transport pathway model and in turn the output of the transport pathway model for lead was used as input to the lead body model. The predicted outputs of the lead body model serve as input to middle-echelon models which assess the impact of the several effects of the stressor lead upon the quality of life.

The EHS and its components utilize the quality of life hierarchy of models as a tool for planning R&D to accomplish the mission of EHS. So the EHS and component organizations exercise various segements of the quality of life hierarchy of models to determine the impacts of particular stressors upon the status of the quality of life. The specific lower-echelon models to be examined and coupled is dependent upon the particular reason for investigation, e.g., if the airborne lead concentration is of concern to NAPCA, the air pathway of the lower-echelon model of transport paths would be coupled with the lead components of the lower-echelon models of the environmental stressors lead and the body model. If the Office of Water Hygiene were concerned with water concentrations of lead, then other couplings between lower-echelon models would be of interest. Also, since, in this example, both NAPCA and Office of Water Hygiene are investigating the stressor lead, there should be an interaction (coupling) between these two operating divisions of EHS to avoid duplication of effort. EHS as the top-echelon model can maintain hierarchical control by interacting with both the EHS organization hierarchy and the quality of life hierarchy.

The Top-Echelon Model

The hierarchical approach allows work to be done at all levels in the model simultaneously. The top-echelon model is the source of ideas for lower models and it dictates allowable assumptions in carving a lower model out of its context with minimum error due to neglected couplings. The top model directs attention to the lower models by the crucial iteration loop between the top- and lower-echelon models. The hierarchy of models serves as a direction stimulus with the capability of a systematic, intelligent, coordinated succession of general analysis by the higher-echelon models and detailed analysis by the lower-echelon models, with each iteration adding information and understanding to the total system which adds to the possibility of gaining more information and thus upgrading the system from the next iteration. Although the work is mainly from the top of the hierarchy down, research and development should be designed to upgrade the models, particularly working below the level of immediate need in order to provide the scientific basis for credibility when needed.

The purpose of the top-echelon model for EHS is to assess the status of the quality of life due to the actions and interactions of all possible stressors which may contribute to the man-environment relationship. Thus, the top-echelon model for EHS would be the evaluation by EHS of "total costs-total benefits" of each stressor with the input to this top-echelon model being the output for each stressor from all lower-echelon models in the hierarchy of quality of life models as generated by the EHS and EHS components. The quality of life assessment for each stressor must be compared and combined to yield the overall status of quality of life from all stressors. The model may ultimately be utilized as a tool to determine the present status of quality of life to predict the future status if no changes are made in our society, and to predict the future status as a result of changing living patterns of our society.

Outline of Approach for Development

Since the top-echelon model for EHS must consider the effect of all stressors and make a comparison of the "total cost-total benefit" ratio due to the effect of each stressor upon the quality of life, the hierarchy of models must have enough detail and be of a manageable size to make the desired comparisons. Several stressors may have to be combined into groups of stressors in the lower-echelon models as the effects of many stressors upon the human populations are not presently known with sufficient detail to warrant an individual description of the stressor at this time. Stressors may be combined by considering existing information on similarities of transport pathways and similarities on their effects on humans.

The evaluation in the top-echelon model of the "total costs" to the "total benefits" cannot presently be measured in a strictly quantitative manner. To evaluate and compare the "total-cost-total benefit" for each stressor as they contribute to the quality of life, a set of qualitative, and quantitative where and when available, indices must be developed. Quality of life indicators and groups of indicators that could be applied to top-echelon evaluations were discussed in Chapter 2. Using these indicators, some of which are quantitative and the rest qualitative, the top-echelon model can initially, although not completely quantitatively, can be used for (1) the evaluation and comparison of "total costs" and "total benefits" of each stressor upon the quality of life so that within the constraint of limited resources, the stressors or group of stressors which require a more detailed examination will be recognized (an estimate of the extent of required detail may have to come from lower-echelon models, but the top-echelon model determines the direction of the effort); (2) the determination of the future assessment of the status of quality of life based upon the assumptions that present levels or rates of changes of stressors continue (the actual estimates for individual stressors or groups of stressors may come from lower-echelon models, but the top-echelon model puts these estimates in the proper perspective with the other stressors); (3) the determination of the future assessment of the status of quality of life if the present levels, rates of change, or classes of stressors should change unexpectedly, by varying degrees.

The terms "total costs-total benefits" have been enclosed by quotation marks in previous paragraphs to denote a specific meaning. These costs-benefits are not meant to be only in terms of dollars, but connote the wide spectrum of costs-benefits which should be included in the assessment of quality of life for man as the center of the ecosystem. Gaffney(5) has very aptly phrased the meaning that is connoted here as "total costs-total benefits". His statement follows:

> "One of the most important functions of economic analysis is to evaluate public policy. Economics, contrary to common usage, begins with the postulate that man is the measure of all things. Direct damage to human health and happiness is more directly "economic", therefore, than damage to property which is simply an intermediate means to health and happiness. Neither do economists regard "economic" as a synonym for "pecuniary". Rather money is but one of many means to ends as well as a useful measure of value. "Economic damage" therefore includes damages to human function and pleasure. the economist tries to weigh these direct effects on people in the same balance with other costs and benefits – to the end of making decisions to maximize net benefits over costs. And, having so decided, one can devise means to compensate the losers from the gains of the winners to the interests of distributive equity".

While EHS can and should be linked to direct output to and input from the lower-echelon models in order to administratively assess the impact of stressors upon the man-environment loop, the EHS should be in constant contact with the EHS organizational components so that EHS can provide guidance to these components based upon higher level EHS decisions and so that EHS can receive the pulse of their components which are sometimes in closer intimate contact to developing problem areas.

For the normal operating situation, the first attribute of the top-echelon model as listed previously is the most important since this is the manner by which the top-echelon model is developed and improved. On the basis of the preliminary assessment of each stressor or group of stressors with respect to the quality of life, the major portion of the assessment and modeling effort by EHS and its operating units may be put into those stressors which have been assessed by the top-echelon model to contribute the most to an inadequate quality of life, while those stressors which are assessed to have the lowest impact upon the quality of life may already be adequately, although with little detail, modeled. More detailed, lower-echelon models would be developed for the "higher impact" stressors and, after the results of the lower-echelon models are fed back to the top-echelon model, another assessment by the top-echelon model of the impact of these stressors upon the quality of life may indicate a redirection of effort or an even more detailed reexamination of the particular stressors. In this iterative, closed-loop utilization of the hierarchical model, there will eventually emerge a top-echelon model for which confident, quantitative evaluations of impacts of stressors can be made.

Until an adequate level of confidence and quantitization is reached in the top-echelon model, the assessment attributes cannot be met on a very confident level. However, in an emergency situation (such as may already exist for some stressors), a much lower level of confidence can be tolerated and the present state of the top-echelon can be used for these latter purposes. It is through the application of a top-echelon model in a hierarchical system that regulations concerning the use of low-sulfur fuel in certain localities could be established. In effect, the top-echelon model evaluation of the "total cost-total benefit" ratio could indicate the amounts of oxides of sulfur in fuel that could produce a specific status of the quality of life to a particular geographical area. The lower-echelon models determine what sulfur level of fuel could produce an oxide level that is acceptable for man and his environment at this location, and this information could be fed back to the top-echelon model which, in turn, leads to the regulation.

The top-echelon model for all stressors has not progressed beyond the qualitative stage in our study. Lower-echelon models were developed for lead to describe the pathways of lead from a limited number of sources to the human population and its deposition in the human body. The assessment of lead upon the quality of life is still a qualitative judgement but at least the results of these lower-echelon models may form the basis for future input to an assessment of the stressor lead upon the quality of life utilizing the top-echelon model.

The initial development of this higher-echelon model and these lower-echelon models should be the foundation of the first and second year schedule for the activities of problem statements and quality-of-life indicators as listed in Table 1. The lower-echelon models should investigate specific stressors in order to systematically develop an initial set of problem statements. The major effort in the development of these hierarchies of models should be conducted by an outside contractor with EHS staff contributing to the development of the models to as great an effort as EHS manpower commitments would allow. The EHS should in any event direct and maintain close liaison with the modeling effort. A level of effort at 5 to 20 man-years per year would be a preliminary estimate. The lower effort is suggested in the initial stages of modeling development. As the complexity of the program develops the higher effort may be required. A higher rate of effort would extend from the initial modeling development in the second and possibly the first year to the succeeding years when the modeling would contribute to (1) revision, addition, and deletion of problem statements; (2) forming the relevancy matrix of problems and indicators; and (3) the rank ordering of problems.

ENVIRONMENTAL HEALTH INFORMATION NETWORK (EHIN)

One of the most important tools of the management information system for EHS is the environmental health information network. It is obvious that all of the functions described in this chapter require ready access to the total information box relevant to the EHS mission. While this base is broad and only a portion of it is under the direct control of EHS, it is important that it be used effectively if the R&D planning and priority setting activities are to accomplish their purpose. The subject of the EHIN and its implementation has been discussed in detail in Volume II and is only mentioned here to emphasize its importance to EHS.

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CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

The major efforts under this study for EHS included (1) an examination of research and development program planning within the man-centered ecosystem context, (2) information network analysis, and (3) model case studies of two environmental stressors, lead and pesticides. Methods to establish priorities for allocation of funds were explored under the R&D program planning efforts. Since EHS is a multiechelon organization with a broad spectrum of responsibilities within the areas of environmental quality and environmental health, no simple method is currently available for priority setting. A comprehensive system can be evolved that includes both R&D planning and priority assessments which is based upon the environmental stressor concept. The use of environmental stressors provides a common basis for integration of planning efforts across environmental problem areas and a means to assure that no significant factors are being overlooked in the plans. The comprehensive system requires the development of problem statements for each of the environmental stressors from the existing information base; a quantitative assessment of the impact of these problems upon man and the quality of his environment through the use of mathematical models; identification of possible alternatives to the solution of these problems; evaluation of the performance expected through the alternative; an estimation of the cost of accomplishment; a rank-ordering of alternatives and problems in terms of priority based upon the impact assessment, the expected performance, and cost; and the selection of the R&D program. Impact assessments of environmental problems would be performed within categories which by consensus indicate the quality of life. Quality-of-life categories would be expected to include indicators of factors such as health, economics, ecosystem structure, and use of resources. Quantitative assessments will only be possible when suitable metrics are available for each of the indicators that are comparable across the categories. Many of these metrics are not currently available but it is expected that they will be developed within the next few years due to efforts within and outside of EHS. Development of mathematical models to describe the man-centered ecosystem should proceed concurrently with the indicator developments to form the comprehensive planning system. The goal for implementation of the comprehensive R&D planning system is to eliminate subjective judgement from performance and priority assessments. In attainment of this goal, expertise from all echelons of the EHS organization should be utilized appropriately.

In the interim while the comprehensive planning system is under development, expert judgment can be used to advantage by EHS for priority setting. Problem statements can be developed for environmental stressors and subjective assessments can be made of the impact of the problems on the various facets of the quality of life. Weights for the various indicators of quality of life can be obtained through use of expert opinion and EHS can combine these weights with the impact assessments to establish priorities. This procedure can be used by EHS to complement the categorical planning presently being done by the components within EHS to move toward the establishment of a comprehensive R&D program within the man-centered ecosystem context. EHS can effectively integrate the program plans of its components in this way and gain experience in the definition and application of the quality of life indices. In this interim period, the R&D planning efforts of the EHS components also can be strengthened through the use of explicit project rating schemes. These schemes can be used with the existing planning efforts and take full advantage of the specific knowledge of the environmental health problems that is possessed by the staff of EHS at lower echelons.

It was further concluded that assistance to EHS management in the area of R&D program planning could be provided by adding an overview environmental health planning function, an impact-assessment function, and a threat-identification and -evaluation function to existing activities. The use of environmental stressors in the implementation of planning in the man – total environment context would be affected through the overview environmental health planning function. An impact-assessment function would provide EHS with a focal point for assessment efforts and would allow the agency to remain abreast of methodologies for assessment and their application by other groups. By assigning a specific responsibility for the identification of potential threats to man and his environment that may arise in the future, EHS can assure itself that significant problems are not being overlooked. These functions will be supported through the development and application of hierarchical modeling, the environmental stressor matrix, and the environmental health information network.

With respect to the latter item, it was concluded that a coordinated information network should be established within EHS consisting of a project information network system, a monitoring and surveillance information system, a scientific and technical information system, and an information resources identification system. A directory of information sources for EHS was prepared as a part of the study to assist in the identification of some of the specific components of this network. Since many of the current and future information handling activities should be computer-based for efficiency, it was concluded that the various facilities should have a stand-alone computer capability in addition to access to a central computer facility. Every effort should be made to attain compatibility of operations among the information systems.

The specific recommendations of the study are:

(1) Comprehensive R&D planning and priority setting based upon quantitative assessments of the impact of technology on man and his environment using quality of life indicators should be a goal for EHS. To accomplish this goal, the definition and acceptance of quality of life indicators, development of a comparable metric system among the categories, and the development of comprehensive impact models will be required.

(2) Since time will be required to accomplish the goal defined above and planning and actions must be taken by EHS in the interim, it is recommended that expert judgment be utilized to assist EHS in the establishment of the priority areas within its R&D programs. The methodology for using this approach would involve assignment of weights to the quality of life indicators preferably through the application of Delphi techniques, making impact assessments of problems upon each indicator category, and combining the weights and impact assessments to yield a priority index.

(3) R&D planning efforts within the components of EHS should be strengthened by the adoption of an explicit project rating system. Categorical planning efforts should continue to be performed at the lowest organizational echelon for it is at that level that the expertise with respect

to problem definition and project rating exists. Definition and application of performance measures for the project rating would be required.

(4) Planning efforts within EHS in the context of man and his total environment can be strengthened and moved in the direction of the comprehensive planning system through implementation of an overview environmental health planning function at the Service level. This function should proceed in planning through adoption of the environmental stressor concept. Program guidance can be given from EHS to lower echelons within this perspective and the detailed plans developed at the lower levels should be reviewed and integrated into the EHS R&D program at the Service level.

(5) An impact assessment activity should be implemented by EHS to improve its ability and sharpen its perspective for making priority evaluations and performing R&D planning.

(6) Through the impact assessment function, EHS should establish a center of technical competence for assessment technology. This center could serve EHS and outside user groups.

(7) In the interest of public protection and long-range planning, EHS should implement a threat identification and evaluation function.

(8) An Environmental Health Information Network (EHIN) should be established. This network should be a coordinated network consisting of a Project Information Retrieval System (PIRS), a Monitoring and Surveillance Information System (MSIIS), and a Scientific and Technical Information System (STIS), supplemented by an Information Resources Identification System (IRIS). PIRS should be a centralized system, operating within EHS. MSIIS and STIS should each remain a federation of centers in a coordinated network structure. Each center or activity should report to the highest authority consistent with its mission, scope, and user audience. IRIS should be a relatively small operation maintaining an inventory of information resources and providing switching and referral service both for the use of the entire staff and for referral of other agencies desiring information to the proper portion of the EHIN network.

(9) Very little analytical response (e.g., state-of-the-art reports, technical compilations, data or design handbooks, and direct answers to technical inquiry) can be expected from the present information resources, both within EHS and outside EHS. EHS should establish Centers of Technical Competence (Information Analysis Centers) in consonance with identification of priorities for various threat areas in order to provide the needed analytical capability.

(10) Accepted thesaurus building rules should be enforced across the board at the EHS level in order to establish some compatibility of the various thesauri in terms of cross-reference techniques and similar devices. Growth of special purpose information systems should not be stifled by the creation of a unified vocabulary.

(11) Various facilities probably can justify, and should have, a stand-alone computer capability in addition to access to the central computer facility, primarily for data processing and research purposes. However, with regard to information systems, every effort should be made to strive for compatibility of operations. The computer facility provided for EHS administrative operations, including information storage and retrieval operations, should equal or exceed the capability of the equipment currently employed by the central computer facility, if that facility cannot be made available to EHS.

APPENDIX A

STRESSORS

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APPENDIX A

STRESSORS

Chemical

Inorganic Compounds

- Acids
  - HCl
  - H_3PO_4
  - H_2SO_4
  - HNO_3
  - HF
- Bases
  - $NaOH$
  - KOH
  - $LiOH$

Organic Compounds

- Acids
  - Formic
  - Acetic
  - Propionic
  - Butyric
  - Oxalic
  - Maleic
  - Succinic
  - Benzoic
  - Oleic
  - Stearic
  - Glutamic
  - Acetyl
  - Salicylic (aspirin)
  - Gibberelic (salts)
  - Ascorbic
- Alcohols
  - Methanol
  - Ethanol
  - Propanol
  - Butanol
  - Ethylene glycol
  - Polyethylene glycol
  - Phenyl ethyl

Organic Compounds (Continued)

- Aldehydes
  - Formaldehyde
  - Acetaldehyde
  - Propionaldehyde
  - Butyraldehyde
  - Acrolein
  - Crotonaldehyde
  - Benzaldehyde
- Anhydrides
  - Acetic
  - Maleic
  - Succinic
- Esters
  - Methyl formate
  - Ethyl formate
  - Methyl acetate
  - Ethyl acetate
  - Methyl propionate
  - Ethyl propionate
  - Methyl butyrate
  - Ethyl butyrate
  - Methyl valerate
  - Ethyl valerate
  - Waxes
  - Butyl acetate
  - Cyclohexyl acetate
  - Dilauryldithiopropionate
  - Dioctyl sodium sulfosuccinate
  - Propyl gallate
  - Glycerides
    - Stearin
    - Palmitin
    - Olein
    - Lecithin
- Fats
  - Vegetable
    - Coconut
    - Palm
  - Animal
    - Butter
    - Lard
    - Tallow

Organic Compounds (Continued)

- Oils
  - Vegetable
    - Castor
    - Olive
    - Peanut
    - Corn
    - Cottonseed
    - Soybean
    - Linseed
    - Tung
  - Animal
- Ethers
  - Diethyl
  - Isopropyl
  - Ethylene oxide
- Aliphatic hydrocarbons
  - Methane
  - Ethane
  - Propane
  - Butane
  - Acetylene
  - Ethylene
  - Butadiene
  - Propylene
  - Paraffin (chewing gum base)
- Aromatic compounds
  - Mononuclear
    - Benzene
    - Toluene
    - Xylene
    - Styrene
  - Polynuclear
    - Naphthalene
    - Anthracene
    - Phenathrene
    - Benz[α]pyrene
- Heterocyclic compounds
  - Thiophene
  - Pyrrole
  - Pyrrolidine
  - Porphyrins
  - Furans
    - Furfural
  - Pyridine
  - Piperidine
  - Quinoline
    - 8-hydroxyquinoline
  - Pyrans
  - Coumarin

Organic Compounds (Continued)

- Heterocyclic compounds (Continued)
  - Alkaloids
    - Coniine
    - Piperine
    - Codeine
    - Heroine
    - Demerol
    - Caffeine
  - Polyvinylpyrrolidene
- Amines
  - Methylamine
  - Dimethylamine
  - Ethanolamine
  - Ethylenediamine
  - Aniline
  - Dodecylamine
  - Ethylenediaminetetraacetate and salts
- Nitrocompounds
  - Nitromethane
  - Nitrobenzene
  - Trinitrotoluene
  - Trinitrobenzene
- Sulfur compounds
  - Thiols
  - Mercaptans
  - Thioethers
  - Sulfonic acids
  - Methyl sulfate
  - Ethyl sulfate
  - Detergents
    - Laurylsulfuric acid
  - Saccharin
- Ketones
  - Acetone
  - Methylethyl ketone
  - Di-isobutylketone
  - Cyclohexanone
  - Mesityl oxide
- Phenols
  - Phenol
  - Cresol
  - Resorcinol
  - Catechol
  - Hydroquinone
  - Pyrogallol
  - Tannic acid
  - Naphthol
- Sugars
  - Fructose
  - Sucrose

Organic Compounds (Continued)

Peroxides

- Benzoylperoxide
- Methylhydroperoxide
- Ethyl peroxide
- t-butyl hydroperoxide

Organic halogen compounds

- Carbon tetrachloride
- Chloroform
- Iodoform
- Ethylene bromide
- Diiodomethane
- Vinyl chloride

Hydrogen

- Hydrogen
- Hydrogen peroxide
- Sodium hydride
- Potassium hydride
- Lithium aluminum hydride

Alkali Metals and Compounds

- Lithium
- Sodium
- Potassium
- Rubidium
- Cesium
- Lithium oxide
- Sodium oxide
- Potassium oxide
- Lithium carbonate
- Sodium cyclamate
- Sodium glytamate
- Potassium nitrate intrite
- Sodium benzoate
- Sodium nitrate nitrite

Alkaline Earth Metals and Compounds

- Beryllium
- Magnesium
- Calcium
- Strontium
- Barium
- Beryllium oxide
- Calcium chloride
- Magnesium sulfate
- Magnesium oxide carbonate
- Calcium gluconate
- Barium perchlorate

Alkaline Earth Metals and Compounds (Continued)

- Calcium citrate
- Calcium phosphate
- Calcium carbide
- Magnesium silicate (talc)

Radon

Boron and Aluminum Compounds

- Boric acid
- Sodium borate
- Alums
- Aluminum hydroxy chloride
- Aluminum hydroxy sulfate
- Aluminum stearate
- Aluminum oxide

Nitrogen and Nitrogen Compounds

- Ammonia
- Nitrous oxide
- Nitric oxide
- Nitrogen dioxide
- Hydrazine
- Methylhydrazine
- Nitrosyl chloride
- Calcium cyanamide
- Ammonium nitrate

Carbon (Inorganic)

- Carbon monoxide
- Carbon dioxide
- Calcium carbide
- Tungsten carbide
- Hydrogen cyanide
- Sodium cyanide
- Ferrocyanides
- Ferricyanides
- Silver cyanide

Coinage Metals and Compounds

- Copper
- Silver
- Gold
- Copper sulfate
- Silver nitrate
- Cyano complexes of gold
- Auric chloride

Zinc, Cadmium, Mercury (and Compounds)

- Zinc oxide
- Zinc sulfate
- Zinc sulfide
- Cadmium sulfide
- Zinc salts of fatty acids
  - Zinc stearate
- Cadmium sulfoselonide
- Mercury
- Cadmium
- Zinc
- Mercurous chloride
- Mercuric chloride
- Mercury compounds
  - Pesticides
  - Drugs

Halogens

- Fluorine
- Chlorine
- Bromine
- Iodine
- Phosgene
- Fluorine dioxide
- Phosphorus trichloride
- Sulfur chloride
- Phosphoryl chloride
- Nitrosyl chloride
- Thionyl chloride
- Chlorates
- Chlorites
- Perhalites

Phosphorus, Arsenic, Antimony, Bismuth, and Compounds

- Phosphine
- Arsene
- Stibine
- Phosphorous
- Phosphates
- Arsenates
- Chlorides of P, As, Sb, and Bi
- Sulfides of P, As, Sb, and Bi

Silicon, Germanium, Tin, Lead, and Compounds

- Hydrides of Ge, Sn, Pb
- Halides of Ge, Sn, Pb

Silicon, Germanium, Tin, Lead, and Compounds (Continued)

- Oxides of Ge, Sn, Pb
- Lead acetate
- Lead sulfide

Sulfur and Sulfur Compounds

- Sulfur dioxide
- Hydrogen sulfide
- Carbon disulfide
- Ammonium sulfide
- Sulfonyl chloride
- Sulfur trioxide

Selenium and Tellurium Compounds

- Hydrogen selenide
- Oxides of Se and Te
- Halides of Se and Te

Chromium, Molybdenum, Tungsten and Compounds

- Carbonyls of Cr, Mo, W
- Chromates and dichromates
- Molybdenum disulfide
- Molybdophosphates
- Tungsten carbide

Uranium and Uranium Compounds

- All compounds (e.g., oxides, halides, nitrates)

Iron, Cobalt, Nickel

- Carbonyls of Fe, Co, Ni
- Iron fumarate

Titanium, Vanadium, Zirconium, Hafnium, Niobium, Tantalum

- Oxides
  - Titanium dioxide
  - Vanadium pentoxides

Manganese, Rhenium

- Oxides
- Permanganates

Ruthenium, Rhodium, Palladium, Osmium, Iridium, Platinum

- Oxides
- Halides

Lanthanides (Lanthanum, Cerium, Molybdenum, Promethium, Samarium, Europium, Gadolinium, Terbium, Dysprosium, Holmium, Erbium, Thulium, Ytterbium, Luticium)

- Oxides

Actinides (Neptunium, Plutonium, Americium, Curium, Berkelium, Californium)

- Oxides

Thorium

- Oxides

Dyes

- Cosmetics
- Foods
- Textiles
  - Nitroso
  - Gambir
  - Nitro
    - Picric acid
    - Naphthol yellow
  - Azo
    - Congo red
    - Orange II
  - Anthraquinone
    - Alizarin
    - Turkey red
  - Indigoids
    - Indigo
  - Triphenylmethane
    - Pararosaniline
    - Aurine
  - Pyronine
    - Fluorescein
    - Eosin
  - Cyanine
    - Quinoline blue
  - Phthalocyanine

Venoms

- Snake
- Insect
- Spider
- Toad

Plant Poisons

- Mushrooms
- Poison Ivy
- Poison oak
- Poinsettia
- Belladonna
- Cassava
- Digitalis
- Dogbone
- Hemlock
- Larkspur
- Locoweed
- Nightshade
- Jimsonweed
- Field bindweed
- Stinging nettle
- Corn cockle
- Canada thistle
- Ragweed

Nerve Agents

Odors

- Mercaptans
- Putresines

Tastes

Explosives

- Gunpowder
- Dynamite
- Trinitrotoluene
- Trimithromethane

Photoreactive Compounds

- Terpenes
- Aliphatic hydrocarbons
- Nitrosyl chloride

Oxidants

Ozone
Halogen oxides
Permanganates
Perborates
Bleaches
Hydrogen peroxide

Antioxidants

Tocopherols
Diphenylamine
Phenyl-α-naphthylamine
α-napthol
Hydroquinone
Butylated hydroxyanisole

Pesticides

Aldrin
Amitrole
Arsenic-containing pesticides
  (inorganic and organic)
Azinphosmethyl (Guthion)
Benzene hexachloride (BHC)
Chlordane
2,4-D (including sales, esters,
  and other derivatives)
DDT (including its isomers and
  dehydrochlorination products)
Dieldrin
Dithiocarbamate pesticides: Maneb
Ferbam, Zineb, etc.
Endrin
Heptachlor
Heptachlor expoxide
Lindane
Malathion
Mercury-containing pesticides
  (including organic and inorganic)
Methoxychlor
Methyl parathion
Mirex
Parathion
Silvex (including salts, esters,
  and other derivatives)
Strobane
2,3,5-T (including salts, esters,
  and other derivatives)
Tetraditon
TDE (DDD) (including its isomers
  and dehydrochlorination products)

Pesticides (Continued)

Toxaphene
Demeton (Systox)
Disulfoton (Di-Syston)
Endosulfan (Thiodan)
Inorganic bromide from bromine-
  containing pesticides
Triazine-type herbicides: Atrazine
Simazine, etc.
Fention
Diazinon
Mevinphos
Carbaryl
Fenoprop
2,3,6-TBA
Fenac

Drugs

Antibacterial agents
Locan anti-infective agents
Antifungal agents
Amebicides
Antimalarial agents
Antitrichomonal agents
Anthelmintics
Anticonvulsants
Anorexiants
Antidepressants
Antipsychotic agents
Antianxiety agents
Antiviral agents
Skeletal muscle relaxants
Sedatives-hypnotics
Analgesics
Narcotic antagonists
Analeptics
Local anesthetics
General anesthetics
Adjuncts to anesthesia
Antihistaminics
Antiemetics
Antitussives
Expectorants and inhalants
Bronchodilators
Topical nasal decongestants
Vasopressors
Antihypertensive agents
Diuretics
Coronary vasodilators
Peripheral vasodilators
Anticoagulants

Drugs (Continued)

- Blood, plasma, and plasma substitutes
- Vitamins used as drugs
- Drugs used in deficiency anemias
- Drugs used in myasthenia gravis
- Antiparkinsonism agents
- Drugs used in glaucoma
- Mydriatics and cycloplegics
- Drugs used in gout
- Adrenal corticosteroids
- Estrogens, progestogens, and oral contraceptives

Drugs (Continued)

- Androgenic-anabolic steroids
- Thyroid hormones and antithyroid agents
- Hypoglycemic agents
- Gastrointestinal agents
- Enzymes used as drugs
- Antineoplastic agents
- Chelating agents
- Immunologic agents
- Radiopaque media
- Miscellaneous agents

Biological

Allergens

- Inhalants
  - Pollens
  - Fungi
  - Vegetable or animal epithelical emanations
  - Dusts
  - Vapors
  - Cosmetics
  - Perfumes
  - Sundry strong odors
- Foods
- Drugs and biological
- Infectious agents
- Contactants
- Physical agents

Infectious microorganisms

- Bacteria
  - Pneumococci
  - Streptococci
  - Microcci
  - Meisseria
  - Haemophilus
  - Bordetella
  - Cornynebacterium
  - Mycobacteriaceae
  - Artinobacillus Mallei and Glanders
  - Enterobacteriaceae
  - Salmonella

Infectious microorganisms (Continued)

- Bacteria (Continued)
  - Shigella
  - Klebsiella Pneumoniae
  - Serratia Marcesens
  - Escherichia Coli
  - Pseudomonas Aeruginosa and Pseudomoniasis
  - Vibrio Comma
  - Brucella
  - Pasteurella
  - Bacillus
  - Clostridium
- Pleuropneumonia
  - Pleuropneumonia
- Rickettsia
  - Rickettsiales
  - Typhus Group of Richettsioses
  - Spotted Fever Group of Rickettsioses
  - Tsutsu Gamushi Rickettsioses
  - Q Fever
- Bedsonia
- Viruses
  - Poxvirus
  - Rabies
  - Herpes
  - Measles
  - Myrovirus
  - Mumps
  - Adenovirus
  - Rhinovirus
  - Picornavirus

Infectious microorganisms (Continued)

- **Viruses (Continued)**
  - **Cocksackie**
  - **Hepatitis**
  - **Arthropod-Borne**
  - **Miscellaneous**
- **Fungi**
  - **Cryptococcus**
  - **Candida**
  - **Blastomyces**
  - **Coccidioides immitis**
  - **Histoplasma capsulatum**
  - **Geotrichium candidum**
  - **Cladosporium trichiodes**
  - **Spotrichium schenckii**
  - **Dermatophytes**

Infectious microorganisms (Continued)

- **Fungi (Continued)**
  - **Predroia hortae**
  - **Aspergillus**
  - **Nocaidia**
  - **Miscellaneous**
- **Parasites**
  - **Protozoan**
  - **Helminths**
  - **Arthropods**
  - **Miscellaneous**

Pests

- **Rats**
- **Insects**

Physical

Fire

Particulates

- Fly ash
- Dust
- Asbestos
- Textile fibers
- Silicon dioxide

Noise

Electricity

- Shock
- Burn

Ultra-sound

Vibration

Radiation

Solid wastes

Explosions

Crowding

SOURCES

Primary

- Agriculture
  - Livestock and livestock products
  - Other agricultural products
  - Agricultural services
- Forestry
  - Forestry products
  - Forestry services
- Fisheries
  - Fishery products
  - Fishery services
- Mining
  - Ferrous ores mining
  - Nonferrous ores mining
  - Coal mining
  - Chemical and fertilizer mineral mining
  - Stone and clay mining and quarring
- Crude oil, petroleum, and natural gas
- Animals
- Natural sources

Secondary

- Construction
  - New construction
  - Maintenance and repair construction
- Ordnance and accessories
- Food and kindred products
- Tobacco manufacturers
- Textiles
  - Fabrics, thread, and yarn mills
  - Misc. textile goods & floor coverings
  - Apparel
  - Misc. fabricated textile products
- Lumber and wood products
  - Household furniture
  - Other furniture and fixtures
  - Paper and paper products
- Printing and publishing
- Chemical processing
  - Chemical and selected products
  - Plastics and synthetic materials
  - Drugs
  - Cleaning preparations
  - Toiletries

Secondary (Continued)

- Chemical processing (Continued)
  - Paints and allied products
  - Petroleum refining and related products
  - Rubber
- Leather
  - Tanning and industrial products
  - Footwear and other leather products
- Stone and clay products
- Primary iron and steel manufacturing
- Primary nonferrous metals manufacturing
- Fabricated metal products
  - Heating
  - Plumbing
  - Structural
  - Containers
  - Screw machine products
  - Metal stamping
  - Engines
  - Turbines
  - Farm machinery and equipment
  - Construction, mining, oil field equipment
  - Materials handling equipment
  - Metal working machinery and equipment
  - Industrial machinery and equipment
  - Machine shop products
- Apparatus, appliance, and machinery
  - Office, computing, and accounting machines
  - Electrical transmission and industrial equipment
  - Radio, TV, and communications equipment
  - Professional, scientific, and control equipment
  - Ophthalmic, optical and photographic equipment
- Transportation
  - Motor vehicles manufacturing
  - Aircraft manufacturing
  - Automobile repair services
  - Travel
- Communications
  - Radio and TV
  - Other

Secondary (Continued)

- Electrical power generation
- Gas services
  - Industrial
  - Transmission
  - Home heating
- Water service
- Waste and waste processing
- National security
  - Member of armed services
  - Concomitant hazards
    - CBW
    - Sonic booms
- Recreation and recreation facilities
- Man

Tertiary

- Consumer products (output from secondary)
- Consumer services
  - Business services
  - Hotel
  - Repair services

Tertiary (Continued)

- Medical and dental services and treatments
- Urban
  - Low income
  - Lack of education
  - Lack of motivation
  - Inaccessible medical services
  - Poor community housekeeping patterns
  - Housing inadequacies
  - Lack of appropriate recreation facilities
  - Lack of medical services and facilities
- Malnutrition
- Accidents
  - Guns
  - Home
  - Occupational
  - Recreational
- Natural disasters
- Rioting
- Crime
- Suicides

TRANSPORT PATHS

- Air
- Water, ingestion
- Water, noningestion
- Food
  - Nutrition
  - Hazard
    - Additives
      - Planned (e.g., cyclamates, MSG)
      - Accidental (e.g., glass dirt)
    - Bacteria
- Consumer products
- Consumer services
- Direct contact
- Vectors
  - Insects
  - Vermin
- Home environment
- Work (and school) environment
- Neighborhood environment
- Recreational environment
- Heredity

EFFECTS

- Direct
  - Physiological
    - Death
    - Disability
    - Discomfort
  - Psychological
    - Disability
    - Impairment
    - Nuisance
    - Aesthetic
- Indirect
  - Economic
  - Political
  - Sociological

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Volume I. Management Assistance and Planning

5. Report Date June 29, 1970

6. Performing Organization Code

7. Author(s) D. L. Morrison, D. B. Menzel, K. L. Nielsen, A. A. Levin, C. W. Hamilton, C. E. Raines, and S. G. Bloom

8. Performing Organization Rept. No.

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15. Supplementary Notes

16. Abstracts

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17. Key Words and Document Analysis (a). Descriptors

Management
Management Analysis
Management Methods
Management Planning
Pollution
Threat Evaluation
Ranking

Forecasting
Mathematical Models
Information Systems
Hazards
Hazardous Materials
Warning Systems
Monitoring

17c. COSATI Field/Group 06/F; 05/B

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~~17b. Identifiers/Open-Ended Terms~~

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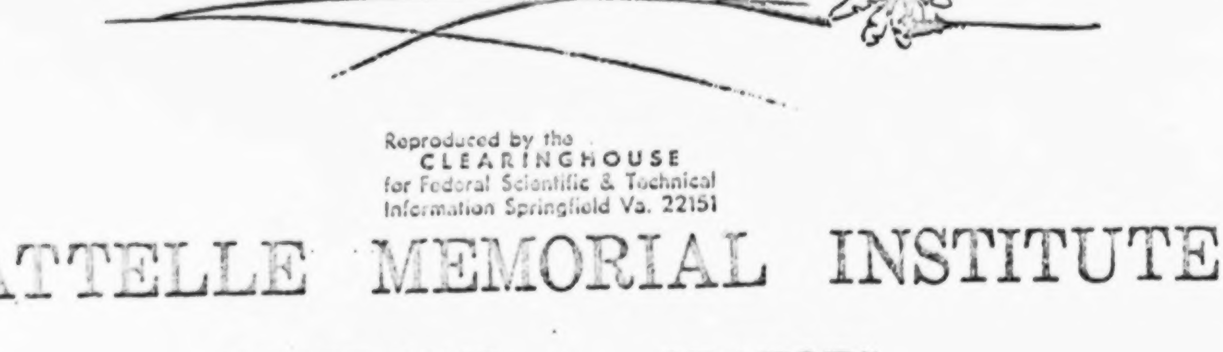

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which were evolved as a part of the overall management-assistance system could be demonstrated and evaluated. Both model case studies also represented a comprehensive review of the environmental aspects of the stressors. The salient features of the two model case studies are described below.

Lead usually occurs as either sulfide ores (galena, PbS) or oxide or carbonate ores (anglesite, $PbSO_4$, and cerussite, $PbCO_3$). Minerals of iron, zinc, silver, copper, gold, cadmium, antimony, arsenic, bismuth, and others may be associated, in varying proportions, in lead ore deposits. The average grade of lead ores mined contains between 3. 0 and 8. 0 percent lead. Mining, smelting and refining, secondary recovery, and imports are the four main sources of lead in this country. In 1969, mine production of recoverable lead was approximately 500, 000 (short tons), with Missouri accounting for 350, 000 tons and Idaho 65, 000 tons. Mine production in the U. S. during the last ten (10) years has exceeded 250, 000 tons annually. The 1969 U. S. supply from mining, primary refining, secondary smelters, and recovery from copper-based scrap amounted to about 1, 540, 000 tons. During the last decade, the U. S. supply annually has been near or beyond 1, 000, 000 tons. Extending this rationale to the domestic lead consumption of primary, secondary, imports, and lead in lead ore entering directly into the manufacture of lead pigment and salts, a figure of 1, 333, 000 tons is obtained for 1969. These figures suggest that even though only a small percentage of lead may enter the environment from the production and consumption cycle, a certain background level of lead would be expected.

An examination of the use pattern for 1969 and the immediate years preceding indicates how lead is added to the environment. Although there have been fluctuations in quantities in the use categories reported, no major changes in the categories themselves have been reported during the last decade. That is, the major uses of lead during 1969 continued to be (in decreasing order) in the production of storage batteries and accessories, gasoline antiknock additives (mostly tetraethyllead), red lead and litharge pigments, ammunition, solder, cable covering, and calking lead. An inspection of the materials requirements and manufacturing processes for the lead-acid storage batteries, e. g., preparation of pasted plates, preparation and assembly of grids, and particle size distribution and grinding of lead oxides revealed cases of lead intoxication in 66 battery-based industries in Pennsylvania. The use of old battery cases for fuel and the resulting lead-containing ash also were identified as environmental hazards of air and soil.

Examination of the use pattern of leaded gasoline additives tetraethyllead (TEL) and lesser amounts of tetramethyllead (TML) indicated that leaded fuels continue to be a major source of environmental lead. Each gallon of today's gasoline contains on the average of 2 to 3 grams of lead (maximum of 4 grams), which adds up to approximately 540 million pounds of lead consumed, according to gasoline sales. An estimated two-thirds of the lead exits through the exhaust, and about half of the exhausted lead becomes airborne, that is, each year about 180 million pounds of lead swirls into the atmosphere. Analysis of atmospheric precipitation samples of lead and other metals collected by a nationwide network of 32 stations throughout the U. S. indicated that the concentration of lead in precipitation correlated with the amount